

Risk assessment and risk management of faecal contamination in drinking water distributed without a disinfectant residual

J. Hein M. van Lieverloo, Gertjan Medema and Dick van der Kooij

ABSTRACT

In the Netherlands, drinking water is distributed with a low or zero disinfectant residual, resulting in a high appreciation of taste and odour. Even more than in countries striving to maintain a disinfectant residual, water companies in the Netherlands should focus on preventing contamination by guaranteeing reliability of infrastructure and hygiene during operations. The Water Safety Plan approach is being tested in several pilot projects, prioritising needs for further optimisation. Incidence of *E. coli* (formerly monitored as thermotolerant coliforms) is low. Only 1 in every 1,000 first tap water samples contains these faecal indicators and only 1 in every 25 repeat samples. Repeated detection of faecal indicators occurs only *c.* five times a year, and outbreaks are rare. Systematic risk assessment, including scientifically based quantitative evaluations, is deemed necessary for effective and cost-effective risk management.

Key words | drinking water, faecal contamination, Hygiene Code, low disinfectant residual, risk management, Water Safety Plan

J. Hein M. van Lieverloo (corresponding author)
Gertjan Medema
Dick van der Kooij
Kiwa Water Research,
Groningehaven 7, 3433 PE Nieuwegein,
the Netherlands
E-mail: Hein.van.Lieverloo@Kiwa.nl;
Gertjan.Medema@Kiwa.nl;
Dick.van.der.Kooij@Kiwa.nl

INTRODUCTION

Drinking water of perfect microbiological quality can deteriorate during distribution due to i) contamination and ii) multiplication of microorganisms using biodegradable compounds present in the water or in the materials in the distribution system. In many countries, maintaining a disinfectant residual in the distribution system is an important measure to control both risks.

In the Netherlands, disinfectant residual concentrations are low (*c.* 0.05 mg Cl₂ l⁻¹) in *c.* 10% of drinking water, but in most of the drinking water a residual is absent. This results in a high appreciation of the taste and odour by the consumer and in the absence or low concentrations of disinfection by-products. Water companies aim to control multiplication of microorganisms by biostability: limiting the availability of substrates for microorganisms in drinking water and materials. Contamination is prevented by ensuring the structural integrity of the infrastructure and by

following hygienic procedures during operations in infrastructure (Van der Kooij *et al.* 1999, 2003). This is necessary to limit risks for public health, corporate reputation and costs of corrective actions. Since 1945, only three outbreaks, all due to cross-connections in distribution systems, have been reported. In 1962, sewage contamination in Amsterdam resulted in six cases of typhus. In 1981, 609 people became ill when the Rotterdam water distribution system was contaminated with wastewater from a marine vessel (Van der Kooij *et al.* 1999). In 2001, a cross-connection with a household water distribution system resulted in approx. 100 households with cases of illness (Fernandes *et al.* accepted). For a population of 16 million and compared with other developed countries, this outbreak frequency and intensity is low. This contribution describes the current status of managing risks of microbiological contamination of drinking water in the Netherlands, focusing

on the development of a Hygiene Code, the Water Safety Plan approach and quantification of risks.

Faecal contamination and pathogens

Risks of contamination of drinking water with pathogenic microorganisms are high when faecally contaminated soil or water is able to enter the distribution system. Other sources of pathogens may be cadavers and employees with an infectious disease. Detection of contamination by drinking water analysis targets indicators of faecal origin (Ashbolt *et al.* 2001). In the Netherlands, as in most countries, drinking water is monitored for the presence of *Escherichia coli*. When *E. coli* is detected, the repeat samples are also tested for other indicators of faecal contamination (enterococci and *Clostridium perfringens*).

The presence of total coliforms in the absence of *E. coli* or other faecal indicators may be the result of a non-faecal contamination but may be also the result of multiplication in the treatment plant or the distribution system (LeChevallier 1990). Contamination with pathogens therefore is not likely and public health is not immediately at risk. The source of a continuous non-faecal contamination may, however, in time become faecally contaminated and the presence of total coliforms calls for a corrective response, albeit less urgent and dramatic than in case of faecal contaminations.

The absence or low concentrations of a disinfectant residual increase the chances of detecting contamination as *E. coli* and total coliforms are not eliminated. A disinfectant residual, however, may also eliminate pathogenic viruses and bacteria (not (oo)cysts of protozoans) during small contamination incidents (LeChevallier 1999; Haas 1999). Preventing contamination remains of paramount importance everywhere (Trussel 1999), especially so when distributing drinking water with a low or absent disinfectant residual.

Faecal contaminations in the Netherlands

Although the absence of *E. coli* is not always sufficient to claim microbiological safety of drinking water (Ashbolt *et al.* 2001), this faecal indicator is widely used in monitoring programmes to verify the quality of the water supply system. In 1996 microbiology of finished and distributed water of 12

treatment plants from the United Kingdom and 8 treatment plants from the Netherlands was compared. Despite the low or zero disinfectant residuals in the Netherlands, the incidence of total coliforms (coli37) and thermotolerant coliforms (coli44, formerly monitored instead of *E. coli*) were fairly comparable and complied with high standards. The mean incidence of coli37 and coli44 in first samples of tap water was 0.7% and <0.1% respectively in the UK systems and 1.2% and 0.15% respectively in the NL systems (Van der Kooij *et al.* 2003). In the Netherlands, regrowth of bacteria in general is limited by limiting concentrations of easily Assimilable Organic Carbon (AOC) (Van der Kooij *et al.* 1999). It is likely that this limits regrowth of total coliforms as well, offering room to focus on *E. coli*.

In 2000, data on *E. coli* (coli44) incidence and faecal contamination incidents were collected from 97 treatment plants (11 of which use surface water) and their distribution systems. Faecal contamination incidents were defined as incidents where repeat samples, taken after detection of coliforms (total or thermotolerant), were positive for coliforms (total or thermotolerant) and at least one sample contained thermotolerant coliforms or other faecal indicators (then faecal streptococci and sulphite reducing Clostridia). The mean incidence of coli44 in first samples of tap water was 0.11% in 1996, 1997 and 1998, the incidence of coli44 in repeat samples was 0.004% (relative to first samples). From 1995 to 2000, nine faecal contamination incidents were reported, of which eight may have led to infection of consumers. Four incidents occurred in treatment plants, the other five occurred in distribution systems. Assuming the selection of 97 systems was representative, supplying *c.* 40% of drinking water, faecal contamination incidents occur 4–5 times each year in the Netherlands. However, the participating water companies were conscious that the documentation and filing of contamination reports was inadequate at that time (Van Lieverloo *et al.* 2003). A more elaborate evaluation of these data will be published separately.

HYGIENE CODE

In 2001, virtually all water companies in the Netherlands joined forces to combine their knowledge and experience into the first part of their Hygiene Code for drinking

water, concerning storage, transport and distribution (Van Lieverloo *et al.* 2002). It resulted in a document, to be updated periodically, providing a basis for managing risks of contamination. The Hygiene Code was fully incorporated into the certification system of contractors and into the training programme for employees of water companies and contractors.

The Hygiene Code was based on a 1986 report providing guidelines for preventing contamination during operations and for disinfecting tools, materials and infrastructure. It was considered an important guideline for hygiene during operations. These parts were updated and supplemented with chapters on infrastructure design as well as detection and correction of contamination. Operational guidelines prescribing quality of backflow prevention, piping and installations in buildings for plumbers and contractors were revised in 2003 (VEWIN 2003).

System of preventive and corrective control measures

Quality of drinking water is attained and maintained by

1. Reliable infrastructure (design, construction and maintenance)
2. Preventive operations, especially by maintaining pressure and working hygienically
3. A detection system for deviations
4. A protective and corrective system to respond to deviations
5. A risk management system acting as a periodical internal audit of steps 1 to 4

Microbiological safety of drinking water is only guaranteed by the preventive components (i.e. 1, 2 and 5). Detection and correction of contamination (components 3 and 4) cannot act as failsafe risk limiting measures, primarily as the water is already consumed once the contamination is detected. These reactive components may however limit the long-term effects of major contamination incidents and act as a verification of the quality of the preventive components. As long as the preventive components are not failsafe, the reactive components remain necessary.

In every component, the Deming circle (Plan – Do – Check – Act) should be the basis of continuous quality management. Figure 1 shows these steps for the five

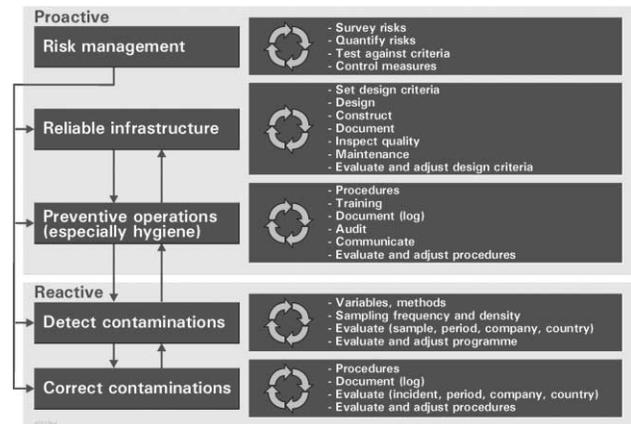


Figure 1 | Basic components of a quality and risk management system for contamination.

components of the quality and risk management system for contamination.

Key guidelines for preventing contamination

Key contamination prevention guidelines in the Hygiene Code (storage, transport and distribution) and Operational Guidelines (connected buildings) are:

- Preventing cross-connections and damage by excavators by systematically mapping mains (publicly available for utilities and contractors).
- Installing backflow and back-siphonage prevention systems, methods depending on risk classes (e.g. break-tanks for connecting hospitals to the distribution system).
- Striving to continuously maintain a sufficiently high water pressure to prevent intrusion of contamination via undetected leaks and failing backflow systems.
- Storing construction materials and tools in closed containers or in fenced areas, elevated from the ground and individually sealed.
- Clearing faecal droppings and cadavers (and surrounding soil) from the work space, taking special preventive arrangements in more heavily contaminated areas.
- Disinfecting tools and (possibly) contaminated materials using a $75 \text{ mg Cl}_2 \text{ l}^{-1}$ solution.
- Intensively flushing ($>1 \text{ m s}^{-1}$), when necessary disinfecting mains after operations.

- Issuing a boiling advice after repairs when microbiological safety is in doubt.
- Cleaning and sampling in the entire area where water pressure was lost during local operations and incidents, at least collecting samples in cases of large areas.
- Preventing intrusion when opening hydrants by guaranteeing a free first flow, flushing out contaminations possibly present in the hydrant (train and motivate fire departments).
- Including cleaning possibilities in distribution system design criteria.

WATER SAFETY PLANS

A risk management strategy known as the Water Safety Plan (WSP) is an important part of the third edition of the WHO Guidelines for Drinking Water Quality (WHO 2004, 2005). The method is based on HACCP (hazard analysis critical control points), developed by NASA and widely used for managing food hygiene (Deere *et al.* 2001; WHO 2003). In the original HACCP system, all parts of a system are evaluated by a multidisciplinary team to identify possible hazards. To minimize the risks of these hazards, a limited number of critical control points (such as disinfection or pasteurisation) are implemented. In the Netherlands, HACCP was first used in 1998 to evaluate and control risks of chemical and microbiological contamination of drinking water. In anticipation of the final WHO Guidelines, implementation of Water Safety Plans has been started by several water companies in the Netherlands, mostly in pilot projects managing risks of faecal contamination.

Current practice in the Netherlands

In the Netherlands, EU regulations for drinking water quality are endorsed, thus forming the basis of the health based targets.

Since the new Drinking Water Decree was issued in the Netherlands in 2001 (Anon. 2001), water companies using surface water (17 treatment plants) or groundwater at risk of contamination with pathogens (*c.* 25 treatment plants, including bank filtration) are required to quantitatively

assess whether the infection risk of the finished water meets the provisional standard of 1×10^{-4} per person per year (Anon. 2001). The method for assessing this risk is in preparation and tested in pilot projects. For treatment plants using groundwater not at risk of faecal contamination (*c.* 210 treatment plants), a research project has started to update risk management strategies. The results of both projects will form the scientific basis to show that source extraction and treatment in the Netherlands achieves the required level of performance.

To guarantee that infrastructure and operation (automated and manual) comply with design criteria, pilot audits are conducted to assess whether systems are implemented to manage these processes. These audits of the quality system are conducted similar to HACCP audits, although the audit is not just focusing on the critical risk control points. Water companies evaluate all risk management systems, as they are striving to maintain a quality level that, at acceptable costs, should prevent even once-in-a-lifetime contamination events.

MaRiskA, a tool for systematic evaluation and documentation

In 2000, the need for a flexible and systematic documenting system was identified. First in Microsoft® Excel, later in Microsoft® Access, a tool was developed for the water companies to document existing hazards and the risk management systems (control measures) operating in their quality management system. It was called MaRiskA (short for Managing Risk Assessment & Risk Control). It combines features of HACCP with features of FMEA (failure mode and effect analysis), a risk management system developed by NASA and widely used in the technological industry (McDermott *et al.* 1996). FMEA scores risks of hazards in designs, production processes or products by multiplying occurrence, severity and detectability, all scored from 1 (good) to 10 (bad). The expected effect of recommended changes is scored as well.

In MaRiskA, the WSP team can enter all automated and manual risk management operations, both condition-independent and condition-dependent. For the condition-dependent operations (manual or automated), the monitoring programme (variable, frequency) can be entered as well

as performance criteria, the corrective actions as a response to deviations and the responsible operator. It is important to be aware that these risk management operations only limit the *likelihood* of the cause of the hazard occurring. The *severity* of the effect can only be limited by following phases in water supply.

The documentation system also enables the WSP team to enter recommendations for improvements in infrastructure or operations, including estimated costs (non-recurring and recurring), priority and planning. Furthermore, for each hazard, there are three opportunities to estimate the risk score (product of likelihood of cause and severity of effect) considering:

1. Just infrastructure, excluding risk management operations (automated and manual)
2. Including all existing systems (both infrastructure and risk management operations)
3. Expected effects of recommended changes in infrastructure and/or operations

Weighing, validating and quantifying risks

A major problem for the Water Safety Plan teams in the Netherlands proved to be the scoring of the risks. The existing scoring tables for likelihood and severity in the WHO manuals (WHO 2004, 2005) or FMEA manuals (e.g. McDermott *et al.* 1996) are not yet considered adequate to fully support objective risk scoring, especially for hazards with a low likelihood of occurrence and a high severity of effect.

Weighing of risks is necessary to effectively limit risks of faecal contamination by prioritising the diversion of financial resources in asset management and operational management. Quantification of risks may be imperative and cost-effective in this process. Currently the WSP teams in the Netherlands discriminate risks into three groups: acceptable ('code green'), possibly unacceptable ('code orange') and unacceptable ('code red'), prioritising within these groups by assigning risk scores. Risks that can only be limited at high costs should be quantified, unless the risk is clearly unacceptable and the costs of the control measure are independent of the height of the risk. Risks that can be

limited at lower costs than the costs of risk quantification, however, clearly need not be quantified.

Experiences in the Netherlands

During Water Safety Plan audits in six water treatment plants and distribution systems of three water companies, conducted from 2001 to 2003, a number of risks were identified, some in all systems. The members of the teams were already aware of most risks before the WSP audit and some improvement projects had already started. The WSP audit, however, provided a good opportunity to focus the attention of the water company on these risks integrally and systematically. The major risks found during the audits are listed below.

Catchment and extraction (including infiltration and reclamation)

- No formal hygiene procedures were implemented, although operated in practice
- Well heads are not always fully closed and therefore are at risk, e.g. during flooding
- Grazing of cattle in infiltration areas with shallow reclamation wells
- The presence of a pressurised sewage line inside a 60 day residence zone of a groundwater extraction area
- Highly probable leakage in vacuum raw water transport systems situated below groundwater levels

Treatment

- Procedures for admission and hygiene during operations by employees, contractors and visitors are not always adequately available and implemented
- Aeration or venting systems are not always constructed adequately
- Efficacy of reversed osmosis was monitored with an online sulphate monitor, but this system was not yet used as an online alarm system for breaks in the membrane units

Storage, transport and distribution

- Process water and finished water reservoirs were not periodically inspected for leaks

- Unnecessary connections between treatment plants or distribution systems existed, increasing risks of spreading contaminations from one system to another
- Trunk mains were not always cleaned after repairs
- A trunk main between two treatment plants is probably leaking and will be contaminated when pressure is lost
- Mains and accessories are not always stored and packed hygienically
- The guideline in the Hygiene Code to flush (if possible) and sample all areas where pressure was lost was not yet implemented in all parts of the organisations
- Most hydrants in place are not equipped with backflow prevention

General

- Improvements in infrastructure, operations and organisation sometimes are designed and implemented too hastily: for example, resulting in employees not being informed, trained, equipped and experienced enough to prevent contamination in the new situation.
- Project management and quality control of operations performed by contractors is not always implemented.
- Many operations are not audited periodically.
- Considering the detection of back repairs in some systems and the lack of periodic inspection in many parts (including online monitors and dosage systems) there is a need for systematic asset management (already in development in most companies).
- Not everyone is aware that water quality monitoring is not effective in limiting risks and that only preventive infrastructure and operations are.

As yet, most risks identified in these projects concern possible secondary contamination. Only a few risks concern the improper operation of treatment processes eliminating pathogens from source water. This probably is the result of the high quality of these existing risk management systems. Risks of secondary contamination generally have been under less scrutiny in water extraction and treatment and were therefore more easily noticed, claiming most of the time of the WSP teams. As awareness of these risks has increased, however, a shift of focus towards treatment operation has already been noticed.

MaRiskA was judged by the water companies a practicable tool both for conducting the WSP audits as well as for documenting the state of risk management systems and recommended improvements.

EC-PROJECT MICRORISK

In 2002 a project called Microrisk, co-funded by the European Commission, started with the objective to deliver a harmonised, scientifically based framework for quantitative assessment of the microbiological safety of drinking water in the EU member states, from source to tap. In one of the work packages, data on faecal contamination incidents and the incidence of *E. coli* (or thermotolerant coliforms) in over 200 distribution systems in Australia, France, Germany, Sweden, the Netherlands and the United Kingdom is evaluated to calculate infection risks. The data evaluation will contribute to the quantitative assessment of the risks of pathogen transmission via drinking water.

CONCLUSIONS

As there are no standards, benchmark values or enough published data available to compare the incidence of faecal contamination incidents or *E. coli* in first samples, it is difficult to rate the relative microbiological safety of drinking water in the Netherlands. However, the general impression of water companies in the Netherlands is that drinking water, distributed with a low or zero disinfectant residual, is not just highly appreciated by consumers for good taste and odour, but also very safe. This is confirmed by high public confidence in the quality of drinking water, despite occasional negative media attention regarding contamination. Public opinion, however, is becoming increasingly focused on limiting risks in general, in particular when these risks are out of the direct control of consumers.

The further development of the Hygiene Code and the implementation of Water Safety Plans as an integral part of general quality systems will lead to more systematic prevention and, when prevention fails, effective correction of contamination. Considering the experiences of the water

companies in the Netherlands in the Water Safety Plan pilots, drinking water is good, but there is still room for optimisation of risk management, leading to a lower frequency of contamination incidents.

Prioritisation and quantification of the risks will contribute to a better assignment of financial resources in design and maintenance processes. Thus, systematic risk assessment and risk management will contribute to the delivery of a good product at the right price.

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