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How current risk assessment and risk management methods for drinking water in The Netherlands cover the WHO water safety plan approach

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ABSTRACT

In the Netherlands, safe and sufficient drinking water is provided to the general population by ten drinking water companies. To guarantee safe drinking water the World Health Organization (WHO) developed a Water Safety Plan (WSP), a Risk Assessment and a Risk Management (RA/RM) framework. The objective of the study was to identify legally required RA approaches, to document application of RA/RM activities at Dutch drinking water companies and to determine to what extent these RA/RM activities as a whole cover all the elements of the WHO WSP approach. This study could be of interest to both managers of large water utilities and decision makers.

The assessment was performed by means of a policy review and interviews with two to four staff members involved in RA/RM from all ten Dutch drinking water companies combined with a joint workshop. The drinking water companies are well aware of the potential hazards and risks that can influence the drinking water quality. To guarantee the supply of safe and sufficient drinking water, the Dutch drinking water sector uses six different legally required RA/RM approaches. This study shows that by using the six legally required RA/RM approaches, all WSP steps are covered. WSP entails a generic risk assessment for identifying all hazards and hazardous events from source to tap, whereas the six legally required RA/RM each focus on specific risks at an advanced level. Each risk assessment provides information on specific hazards and hazardous events covering a part of the water supply chain. These legal requirements are complemented with additional RA/RM activities at sector and water company level such as codes of practices and standard operating procedures. The outcomes of all RA/RM approaches combined provide information from source to tap. When using multiple RA/RM approaches, it is crucial to share and combine information derived from the different activities.

1. Introduction

Drinking water is the final product of the production chain – from source to tap – which is monitored to ensure drinking water of sufficient quality and thus protect public health (WHO, 2015). Although monitoring of drinking water as a final product has been the norm to determine if drinking water is safe and clean, over the past decades it has become clear that this monitoring can often be too little and too late (WHO, 2015). Consequently, the detection of risks might be too late or might not happen at all, which may lead to infectious diseases or other negative health effects (WHO, 2015). Therefore, a preventative risk based approach for the whole drinking water supply as a system has been introduced, including risk assessment (RA) for identification of the risks and risk management (RM) for managing the risk, generally referred to as an RA/RM approach. RA/RM approaches have been introduced worldwide, not only for drinking water but also for other waters, such as bathing waters (bathing water profiles) and shellfish production areas (sanitary surveys), (WHO, 2010; EU, 2006).

In 1994, Havelaar explored the application of HACCP (hazard analysis and critical control point), a food safety management system, to drinking water supply systems (Havelaar, 1994). In some countries, for example Switzerland, the drinking water supply was also regulated through the law for food protection and therefore already required HACCP. Between 1999 and 2001, an international group of experts discussed the potential to increase consistency in approaches of assessment and management of water-related microbial hazards, which

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led to the 'Stockholm Framework' (Fewtrell and Bartram, 2001). This further explored the application of HACCP to the drinking water supply. The third edition of the WHO Guidelines for Drinking-Water Quality (WHO, 2004) included the 'Framework for Safe Drinking-water', which encompasses setting health-based targets, an RA/RM approach and independent surveillance. The risk management approach was referred to as a water safety plan (WSP). At the same time, the International Water Association published the Bonn Charter for Safe Drinking Water, which provides a high-level framework describing the operational and institutional arrangements that are basic requirements for managing water supplies from catchment to consumer (IWA, 2004). Various publications provided further support for the implementation of a WSP, such as the WSP manual (Bartram et al., 2009) and WSP for small community water supplies (WHO, 2012). WSPs require an RA including all steps in the water supply from catchment to consumer, followed by implementation of control measures and by improvement with a focus on high priority risks (WHO, 2011; WHO, 2017a).

Over the last decade, WSPs have been successfully implemented in both high- and low-income countries. To date, WSPs are being implemented to varying degrees in 93 countries globally, with 30% of countries at an early adoption stage; 46 countries report having policy/regulatory instruments that promote or require WSPs and in another 23 countries such instruments are under development (WHO, 2017b). There are reports of many benefits from WSP application, such as improved system management of water supplies; increased awareness, knowledge and understanding among staff; improved communication and collaboration with other stakeholders and also within water supply companies; and improved water quality (Gunnarsdottir et al., 2012). The way WSP is applied varies with the development level of the water supply and the resources available.

In the Netherlands, drinking water is produced from surface water (38%) and groundwater (62%) to provide the Dutch population with safe, clean and sufficient drinking water (VEWIN, 2017). In the Netherlands, only a few hundred small private supplies, mainly campsites and recreational parks, produce drinking water to supply staff or guests (ILT, 2018). Ten very large public drinking water companies serve the general population, serving between 435,000 and 5.7 million people each (VEWIN, 2017). These drinking water companies provide drinking water by collecting and treating groundwater or surface water and providing it to the customer's tap via a pipeline network. The drinking water production and supply are prone to contamination with microbial and chemical hazards from humans and their activities in the environment or from naturally occurring contamination (WHO, 2004). Various hazardous events can impact the chemical, microbial or physical quality of the drinking water somewhere between the source and the tap, such as sewage discharge, chemical waste disposal and damaged pipes in the distribution network due to external construction works (WHO, 2004). The production and distribution of safe and sufficient drinking water by drinking water companies in the Netherlands is regulated under the Dutch Drinking Water Act (I&W, 2009). The human Environmental and Transport Inspectorate (ILT) of the Ministry of Infrastructure and Water Management (I&W) is the governmental body that supervises the water supply companies, with the Minister of I&W having the ultimate responsibility for ensuring safe drinking water (I&W, 2009).

Although there is no specific policy or legislation mentioning the specific wording WSP in the Netherlands, the policy and legislation is based on the same principles of RA/RM. Guaranteed continuous drinking water supply and quality of drinking water have always been the focus of the national policy and the Dutch drinking water companies (de Moel et al., 2006). In 2001, already before WHO and IWA launched the WSP, the first de facto WSPs were initiated by the drinking water utilities in the Netherlands (Smeets and Puijker, 2013). The software program MarRiskA (Van Lieverloo et al., 2003) was developed as a tool to facilitate this RA implementation in a uniform format. A number of companies collaborated on the development of tools at the international level such as the TECHNEAU Hazard Database (Beuken et al., 2008). Until 2010, different drinking water companies completed approximately seventeen WSPs applying the principles of the WHO approach (Smeets and Puijker, 2013). In 2013, the Dutch water companies discussed the need to uniformly implement a WSP as a framework for RA/RM (Smeets and Puijker, 2013). At that time, it was considered an extra burden on top of existing risk management requirements and practices with no added benefit, as most of the steps in WSP were presumed to already be in place.

This study was performed by the National Institute for Public Health and the Environment (RIVM) and KWR Watercycle Research Institute (KWR) on behalf of the Ministry of I&W. The goal of this study is to identify applied RA/RM components in policy and legislation and activities at all ten Dutch drinking water companies and to determine to what extent these RA/RM activities as a whole cover the elements of the WHO WSP approach.

2. Methods

To construct an overview of all RA/RM approaches and activities, information was gathered in 2016 - 2017 by

1. Conducting a policy review to identify all relevant legislations and policy on RA/RM for drinking water
2. Identifying all RA/RM activities conducted per drinking water company
   - Staff members from drinking water companies were selected based on their experience in RA/RM. They were interviewed using a questionnaire to identify all RA/RM activities applied within their drinking water company. The questionnaire was designed according to the steps of a WSP.
   - Based on the policy review and the interviews, a draft overview of the data per company was made and sent back to the interviewees for feedback. After the collection of all feedback, the data from all drinking water companies was collated to provide an overview of all RA/RM activities with similarities and differences between drinking water companies.
   - A workshop was organized to discuss the results of the interviews and to examine the current use of risk-based management in the production of drinking water.

The information gathered from the policy review and interviews were examined to determine to what extent the RA/RM approaches and applied activities cover the WHO WSP approach according to the WSP Manual (Bartram et al., 2009) and to identify any gaps, possible improvements and best practices.

3. Results

3.1. Policy review: Legal requirements for risk assessment and risk management

In the Netherlands, legislation does not mention WSP specifically, but prescribes RA/RM in legislation and policy. Based on the policy review, the following RA/RM approaches were identified:

- Quantitative Microbial Risk Analysis (QMRA)
- Drinking water protection files
- Disturbance Risk Analysis (DRA) as part of the Drinking Water Supply Plans
- Legionella Prevention Control in drinking water installations
- Code of hygienic practice for drinking water supply
- Monitoring program drinking water quality – risk based

All RA/RM approaches corresponded to certified quality management systems and standards, which are legally required. All water

companies were certified according to the new ISO 9001: 2015 standard (ISO, 2015a). RA/RM activities are an explicit part of this new version of the ISO 9001 standard for quality management, and ISO 14000 offers an environmental framework for RA/RM (ISO, 2015b). Other legal requirements support RA/RM and contribute to the protection of drinking water quality from source to tap. Examples are requirements for intake of raw water, a specific requirement with regard to identifying compounds of concern and hygienic requirements for materials and chemicals used in the drinking water system.

3.1.1. QMRA

The Dutch Drinking Water Act (I&W, 2009) prescribes that the index pathogens (Entero)viruses, *Cryptosporidium*, *Giardia* and *Campylobacter* should not exceed an infection risk of one infection per 10,000 individuals per year. To demonstrate the microbial safety of drinking water, Dutch drinking water companies must conduct a QMRA at least every four years for these so-called index pathogens. Since 2005, Dutch drinking water companies have conducted QMRAs as described in the Dutch Inspectorate Guideline 5318 (Anonymous, 2005) for all surface water production plants. The QMRA includes a system description, as well as the identification of possible microbial hazards and hazardous events and a monitoring requirement from source to treatment. Drinking water companies using surface water for the production of drinking water estimate the infection risk using the computational tool QMRAspot (Schijven et al., 2011). The estimated risks are evaluated and discussed in close collaboration between drinking water companies, RIVM and ILT (Bichai and Smeets, 2013). QMRAspot facilitates the evaluation of effective preventative measures and supports policy makers and other involved parties in risk prioritization and the formulation of mitigation strategies. ILT advises the drinking water companies when to take action or develop an improvement plan.

3.1.2. Drinking water protection files

As described in the policy brief on Drinking Water (2015), competent authorities and drinking water companies agreed to jointly set up drinking water protection files for intake zones. The drinking water protection files contain information about the quality of the resources, sources of pollution and the vulnerability of the water system. Within the drinking water protection files, risks regarding all possible contaminants of the drinking water are assessed. Based on the assessment, different stakeholders are involved to identify measures, aimed at prevention and risk management. Monitoring the control measures and a regular update of the drinking water protection file are also part of this approach. The drinking water protection files have to be updated every six years (Wuijts et al., 2017). In the Netherlands, the drinking water protection files are part of the implementation of articles 7, 8 and 11 provisions of the Water Framework Directive. The protection files are also an instrument to work together and exchange information between the drinking water companies, competent authorities responsible for Water Framework Directive implementation and other stakeholders. The drinking water companies use the outcomes of the analysis for their risk based monitoring programs.

3.1.3. Disturbance risk analysis

As a requirement in the Drinking Water Decree (I&W, 2011a), drinking water companies draw up a DRA as part of the drinking water supply plan. They assess the risks of a long list of threats and hazards which potentially affect the quantity or quality of the water supply. Based on the outcomes of the DRA, additional control measures are included in the drinking water supply plan, to minimize risks for the public drinking water supply. These drinking water supply plans (including the assessment) have to be revised every four years and are approved by the ILT.

3.1.4. Legionella prevention control in drinking water installations

Legionella prevention control is mandatory for drinking water installations in buildings used by people with higher risk for legionella infection, such as hospitals, retirement homes, hotels and swimming pools (I&W, 2011a). The owner of the building is responsible for assessing the risks according to Dutch regulations (microbial hazards), which should be done by a certified person or organization. Furthermore, a control plan is required that describes control measures such as flushing, temperature control and a monitoring program.

The drinking water company supplying the water inspects whether the owner of the building has fulfilled their responsibility according to Legionella prevention. Non-compliances within the monitoring of Legionella need to be reported to the ILT. If improvement is necessary after the inspection by the drinking water company, an improvement plan has to be made by the owner.

3.1.5. Code of hygienic practice for drinking water supply

The Dutch Drinking Water Decree (I&W, 2011a) refers to European standards and Dutch codes for working hygienically (Meerkerk, 2016). The code of hygienic practice “Drinking water”, was made by the drinking water companies as an integral system for quality management and risk management to ensure the microbiological safety of drinking water during storage and distribution. The main topics of this code of hygienic practice are:

- Proper infrastructure and hygienic requirements for materials and chemicals (I&W, 2011b)
- Preventive management for working hygienically
- Sensitive detection systems for contamination and deviations
- Effective corrective actions for contamination and deviations
- Periodic inventory and evaluation of risks
- Instructions and training for employees to do construction work according to hygienic rules

3.1.6. Monitoring program drinking water quality

The Drinking Water Decree prescribes that drinking water should meet the regulation, and by complying to the regulation the drinking water companies ensure the supply of safe drinking water. Drinking water companies are required to set up an annual monitoring program as prescribed by the regulations. The monitoring program, based on the assessment of the microbial, chemical and physical risks as described in the Directive 2015/1787/EC (EU, 2015), entails monitoring from source to tap. The monitoring programs are updated annually, and have to be approved by the ILT. In addition to these monitoring programs, the drinking water companies perform screenings. The legislation prescribes alert values for known substances and for unforeseen substances to trigger further research to identify the risk.

3.2. Identify RA/RM activities per drinking water company

Two of the authors interviewed two to four staff members who were involved in RA/RM within their company. Dutch drinking water companies were obliged to carry out the legally required RA/RM approaches, which was underlined during the interviews with all drinking water companies. Furthermore, the representative staff members provided us with information on sector- or company specific RA/RM activities per WSP step they practiced which was complementary to the legal requirements.

All information was documented by the interviewers, and sent to the interviewees for feedback. After collecting all feedback, the data from all drinking water companies was collated to provide an overview of all RA/RM activities. Similarities and differences between drinking water companies were thus identified. The results from the interviews and policy review were presented at a workshop organized at RIVM, which was attended by 52 people from the Ministry of I&W, drinking water companies, ILT, RIVM and KWR. During the workshop, integrated RM, risk analyses and data and policy on RA/RM were discussed in breakout sessions. The moderators of the breakout sessions

Textbox 1
Some examples of control measures in place

Some examples of control measures in place to prevent contamination of drinking water.

Catchment and abstraction.

- Groundwater protection area
- Instruction from Technology platform for transport, infrastructure and public space on careful digging process
- Management agreements regarding existing and known contaminants in groundwater protection areas
- Manure regulation policy
- Requirements for intake of raw water
- Specific requirement with regard to identifying compounds of concern
- Policy on discharge permits (reducing the amount of pesticides)
- Agreements with the Safety Regions for timely alerts
- Policy for soil protection
- Protection against (deliberate) pollution and calamities
- Association of River Waterworks (RIWA) and/or Maas alarm model for source water monitoring
- Drinking water protection files
- Policy for water protection

Treatment and distribution.

- Treatment process (e.g. UV disinfection, slow sand filtration, soil infiltration, ozonation, activated carbon filtration and advanced oxidation process)
- Products and chemicals in contact with drinking water used by the water supplier need to be certified according Regulation [I&W, 2011b]
- Preventative maintenance
- Process automation system
- Work permit for external employees (e.g. construction)
- Limited access for employees and additional rules for visitors
- Hygienic areas: Color code (e.g. blue – raw water; red – disinfected water)

Consumers.

- Preventive drinking boil water notice

collected the information and presented the outcomes at the end of the workshop. The next paragraph contains an overview on which RA/RM activities were undertaken per WSP step, based on the policy review, interviews and workshop, and we outline experiences from the drinking water companies.

3.3. Coverage of each step of the WHO WSP

All drinking water companies reported teams that focus on RA/RM (**WSP step 1**), but sometimes different people or teams were involved in the different RA/RM activities as well as all legally required RA/RM approaches. The teams were mostly internal teams of a broad and multidisciplinary composition, and occasionally the teams were assisted by external experts. Two drinking water companies had an overarching team responsible for RA/RM, whereas the other eight water companies had several teams involved in RA/RM. For communication between different teams all companies nominated a linking pin: a person or a department.

Five of the legally required RA/RM approaches prescribed a system description and all ten drinking water companies had a complete and up-to-date description of the drinking water system (**WSP step 2**). The system description from source to tap also included working practices and/or procedures and was digitally available at all drinking water companies. Over 20 different software systems for the system description were present for the different components (source-treatment-tap) and sometimes even within one component various systems were available to record the data. Examples of these software systems were geographical information systems, design software and network information systems. Because of the use of different software systems for the water supply system descriptions from source to tap, these systems were not automatically linked to each other. Only three companies had linked all system descriptions from source to tap (including processes and procedures).

All drinking water companies have always been aware of the potential risks to the drinking water supply and have put a lot of effort towards reducing these risks. Besides all six legal requirements, the Dutch drinking water companies had sector or company specific activities for identifying hazards and hazardous events and for performing a risk assessment (**WSP step 3**). Examples applied in some drinking water companies are:

- Internal audits focus on irregularities, incidents or possible risk and follow up.
- Inspections and technical screening
- Trend analysis for identifying future risks.
- Risk analyses for asset management, such as Failure Mode Effect & Criticality Analysis, HAZard and OPerability study.
- A WSP approach for identifying hazards and hazardous events from source to tap.
- Risk analyses for their monitoring, and screenings for non-regulated substances.

All drinking water companies prioritized the risks. However, there were many different ways of weighing the risks, varying from quantitative risk assessment to expert opinion. For some assessments, the method for weighing the risks varied between drinking water companies, but also between the prioritization methods used within one drinking water company. Documentation of the identified risks varied per drinking water company, depending on the available systems: one central database or different files or systems per RA/RM approach.

The drinking water companies had many different control measures in place to reduce potential risks (**WSP step 4**). Control measures were prescribed by the legal requirements for RA/RM, but also by other legal requirements, advisory guidelines or company specific management

procedures. During the interviews, examples were given of control measures in place to prevent contamination of drinking water by the drinking water companies. Textbox 1 contains some examples.

To ensure that control measures work effectively, the Dutch drinking water companies assess the effectiveness of control measures. For this assessment, field data from the specific drinking water company is most valued to assess the efficiency of control measures, followed by pilot data generated by the specific drinking water company. If location specific data are unavailable literature, study outcomes or trend analyses are also considered.

Within the sector, the drinking water companies work together in research to validate control measures (Brouwer et al., 2018). Examples of such joint research are reduction of pathogens by slow sand filtration (Schijven et al., 2013), soil infiltration (Hornstra et al., 2018) or UV disinfection (Hijnen et al., 2006) and breakdown of micro-pollutants by UV-peroxide advanced oxidation (IJpelaar et al., 2010).

As for the legal requirements for risk assessment, all drinking water companies also prepared improvement plans for potential risks identified (**WSP step 5**) based on these company specific risk assessments.

Apart from the DRA, all legal requirements prescribe the microbial and physico-chemical parameters to be monitored for different purposes, such as source water quality monitoring, operational and verification monitoring. For operational monitoring (**WSP step 6**) the legislation prescribes parameters to be tested for monitoring of control measures. Examples are measuring pH, turbidity, flow rate, dosing of chemicals and pressure, which are measured online at most water companies. Besides measurements, also visual inspections are periodically done for both infrastructure and procedures.

Furthermore, all drinking water companies had additional water quality monitoring at the source, treatment and distribution (extra-legal measurements), such as additional samples, biomonitoring and screening for unknown and non-standardized emerging substances. All ten drinking water companies reported procedures for abnormalities in the control process and water quality measurements. In some drinking water companies, the completion of the procedures for abnormalities differed, but all operated 24/7. In all drinking water companies the corrective action procedures were known to act on anomalies.

The data, derived from monitoring programs, were stored in various data collection systems and databases. Six drinking water companies indicated that the (monitoring) data were already linked, but that there was room for improvement as well. Those drinking water companies that had not linked (monitoring) data had the intention to link information from the databases.

Effectiveness of the WSP was verified using three different methods: compliance monitoring, auditing RA/RM and customer satisfaction surveys (**WSP step 7**).

1. Compliance monitoring was used to determine the effectiveness of RA/RM-activities. Therefore, all drinking water companies showed the use of legal requirements, such as water quality monitoring, including QMRA, and the performance comparison (benchmark), including substandard delivery minutes to verify the effectiveness of the RA/RM activities. Legionella prevention prescribes monitoring at household level for the detection of *Legionella.* In addition, specific water quality monitoring, registration of failures and technological audits were shown to be used to determine the effectiveness of the RA/RM-components. The Drinking Water Decree describes the framework for reporting defects to ILT (I&W, 2011a).
2. With the legal requirement of ISO 9001 (for both versions 2008 and 2015) the processes around drinking water supply were subjected to internal and external audits (ISO, 2008; ISO, 2015a). Internal and external audits were also obligatory for ISO 14000 (ISO, 2015b).
3. Customer satisfaction surveys were done by all drinking water companies as part of the performance benchmark (VEWIN, 2017). All drinking water companies also have 24/7 customer complaints services. Evaluation of the customer satisfaction surveys provided information on customer perception of water quality.

The Drinking Water Act requires drinking water companies to have certified quality management systems (I&W, 2009). Management involvement is important for creating a framework for the implementation of RA/RM by addressing financial and other resources. Furthermore, management plays an important role in the development of procedures and communication in identifying potential risks, and improvement in the organization (**WSP step 8**). As part of the quality management system, all drinking water companies have standard operating procedures for their daily work. Furthermore, the legislation prescribes to only test water at accredited laboratories that automatically should have standard operating procedures. The code of hygienic practice for drinking water supply prescribes procedures for quality and risk management. The Dutch Drinking Water Act holds legal requirements with respect to an uninterrupted supply of drinking water during 'normal or undisturbed' as well as 'disturbed' circumstances, in the present as well as in the future. These requirements mostly focus on water quantity and include elements like emergency response, security of the water supply system, and the supply of drinking water during failure of the water supply system. All water supply companies have implemented security and contingency plans.

All drinking water companies carried out many supporting activities to raise awareness of the risks of unsafe drinking water and the risks of contamination (**WSP step 9**). In two legally required approaches, the code of hygienic practice for drinking water supply and drinking water protection files, supporting activities were explicitly mentioned. Furthermore, the interviewees provided several RA/RM supporting activities, see Textbox 2.

Periodic reviews were carried out to keep the system description up-to-date (**WSP step 10**). The validity of the system description for the distribution network was checked and corrected as part of the daily activities where necessary, using tablets so that changes or observations in the field could be included directly in the description. The system descriptions for abstraction and treatment were stable and therefore up to date. Periodic reviews also took place for the legally required RA/RM approaches, including RA and improvement plans. The specific cycle of review per legally required RA/RM is described above (see legal requirements for RA/RM).

Since the 1990s, the drinking water companies had developed guidelines for the continuity of the drinking water supply and for the water supply during emergencies and disasters (**WSP Step 11**). As mentioned in WSP step 8, all drinking water companies had implemented security and contingency plans. An incident should be reported to ILT, and afterwards the RA should be revised and information given on how to prevent re-occurrence of this incident.

Coverage of WSP steps by the six legally required RA/RM approaches.

The six RA/RM approaches described in this study cover different steps of the WSP approach which is shown in Fig. 1. For all approaches (1–6) a team was assembled and hazards and hazardous events were identified to assess the risk. The system description was carried out in 5 RA/RM approaches. QMRA (1) and Drinking water protection files (2) covered most WSP steps, as they cover 10 and 11 WSP steps respectively. Fig. 1 shows that only one RA/RM approach (2) covered all of the 11 WSP steps, and a combination of RA/RM approaches was needed to fully cover all WSP steps. Sector- and company specific RA/RM activities complemented the six legally required RA/RM approaches and covered the different steps as well.

The six legally required RA/RM approaches contained advanced and detailed risk assessment methods, especially developed to generate more information on specific hazards or specific parts of the water supply system. Although all 11 WSP steps were covered with these six legally required RA/RM approaches, none of these approaches individually:

Textbox 2
Some examples of supporting activities, given during the interviews with the drinking water companies.

Some examples of supporting activities of the drinking water companies.

Communication with consumers.

- Public participation for sampling
- Newsletter
- Website that contains information from source to tap. These websites also contain public water quality data and information about possible faults, disconnection and activities
- Social media (Twitter, Facebook) and email to inform and engage consumers
- Open days, information sessions, campaigns, meetings or visitor centers

Training.

- Training, training modules and courses for employees and subcontractors
- Certification of subcontractors to demonstrate awareness of the risks to drinking water before starting restoration and maintenance work
- Training and exercises on what to do in case of an emergency or disruption

Communication with different stakeholders.

- Creating awareness and sharing information with municipalities, provinces, water authorities, health safety regions and related sectors such as other utilities or railroad companies
- Regular contact with fire brigades, police and nature conservation organizations

- identify microbiological, chemical as well as physical hazards;
- cover the complete drinking water supply chain and;
- are applicable to all drinking water supply systems

This showed that multiple RA/RM approaches were needed to provide full information on all hazards and hazardous events from source to tap by combining the specific and detailed information gathered by the individual RA/RM approaches. By using multiple RA/RM approaches as described above the following challenges were observed during the inventory:

- sharing knowledge between the different RA/RM approaches due to the involvement of different teams
- combining information due to multiple systems used for data collection in the different RA/RM approaches
- prioritizing risks based on different methodologies for assessing and rating the risks

4. Discussion

Baum and Bartram stated that guidelines, regulations, tools and resources are elements of the enabling environment that encourage adaptation and implementation of WSPs in high-income countries (Baum and Bartram, 2018). In the Netherlands, legislation is available

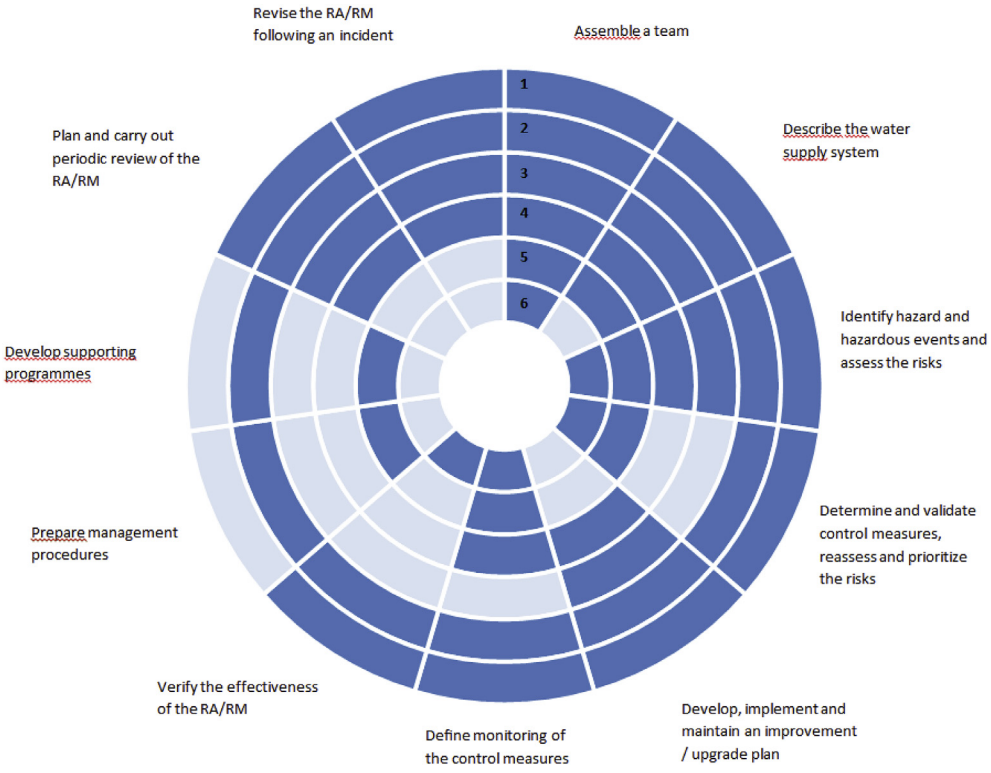

Fig. 1. Schematic overview of the WSP steps covered (dark blue) or not covered (light blue) by the six legally required RA/RM approaches represented per ring: 1. QMRA; 2. Drinking water protection files; 3. DRA; 4. Legionella prevention; 5. Code of hygienic practice for drinking water supply; 6. Monitoring program drinking water quality. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

for multiple RA/RM approaches, but not specific for WSP as described by WHO (WHO, 2004; Bartram et al., 2009). While guidelines and regulations promote the uptake of risk management such as WSP, other conditions such as cultures and norms also influence risk management practices (Amjad et al., 2016). The focus of the policy and the legislation in the Netherlands is on continuous drinking water supply of good quality. The focus of Dutch drinking water companies has always been on the quality of drinking water and continuous improvement of the water supplied. This has resulted in a variety of RA/RM methodologies used in the Netherlands, those legally required, sector specific and company specific ones. The drinking water companies continuously improve these different specific RA/RM methods by collaboration between drinking water companies, external experts and government. The monitoring program within QMRA is adapted to include worst-case scenario, so-called peak events. This is in line with recent development for risk-based monitoring (WHO, 2015; EU, 2015). Another example is including climate change scenarios in the DRA to identify all hazards and hazardous events that affect the quantity or quality of the water supply. This corresponds to climate resilience recently incorporated into the WSP (WHO, 2017c).

The WSP approach is a very useful overarching approach for a systematic RA/RM from source to tap, to identify all hazards and hazardous events. For drinking-water systems, risk assessment is an integral part of WSPs, and many different risk assessment methodologies from more simple to complex are available such as sanitary inspections, WSP risk matrix and QMRA. In the Netherlands, the six legally required RA/RM approaches contain advanced and detailed risk assessment methodologies. Combining all outcomes from these RA/RM approaches provides information on all hazards and hazardous events from source to tap and can be used as input for an overarching framework such as WSP. Comparable results were reported by Setty et al. (2019) showing that individual utility approaches need not be limited to one risk management programme as alternatives can be complementary. However, some challenges of using multiple RA/RM approaches were identified, compared to using a single approach, such as WSP. The first challenge of using six different RA/RM is combining and centralizing all identified risks and improvement plans from source to tap derived from the different RA/RM, e.g. using one centralized system or document. Using one RA/RM approach from source to tap, all information from source to tap is collected together. Another challenge is that the different risk assessments, used within one drinking water company, have many ways of weighing the risks, varying from quantitative risk analysis to expert opinion. It is important that drinking water companies can compare risk scores generated by different assessments to prioritize the most important hazardous events (based on severity and likelihood), instead of having separate risk outcomes. Within the WSP framework, not much guidance is given on how to include different assessment methods and how to prioritize. The European Standard EN 15975–2 is an appropriate option to provide such guidance, and incorporates fundamental elements of RA/RM (EN, 2013).

Compared to the WSP approach, different teams were involved in different RA/RM activities at Dutch drinking water companies, and therefore it is crucial to have an appointed responsible linking pin, as person or department, to share this information and harmonize how to use and interpret results from different risk assessments within one drinking water company. Another challenge is how to deal with all existing information and how to combine information between different systems, e.g. system description from source to tap. Traditionally, drinking water companies have separate pillars for abstraction, production and distribution, and therefore combining the system descriptions and monitoring data from these pillars would be an improvement for the drinking water companies. The obligation for risk based monitoring from source to tap is an important motivation for combining these pillars in the context of a risk based monitoring program.

Globally, the goal of the drinking water companies is to provide safe water, and therefore many steps of the WSP might be applied already even though the drinking water companies are not aware that they are carrying out parts of a WSP. An inventory, as shown in this study, of which steps of the WSP are already covered by the drinking water company is essential to show what has already been tackled and how, and what has not (completely) been tackled. As shown in this study, all steps of the WSP approach as described by WHO are covered by the legal requirements for RA/RM and even strengthened by sector and company specific RA/RM activities.

Of the countries that provided information on urban versus rural WSPs, 62% reported implementing WSPs in both urban and rural settings, reaffirming that WSP principles apply across all system types and sizes (WHO, 2017b). Not all six legally required RA/RM approaches are applicable to all system types and sizes. For example, in The Netherlands QMRA is legally required for drinking water companies using surface water or vulnerable groundwater sources for the production of drinking water. However, the tool QMRAspot only supports drinking water companies using surface water. Representatives of the drinking water companies, regulators and knowledge institutes are investigating how QMRA can be achieved for drinking water companies using vulnerable groundwater sources. Furthermore, the six legally required RA/RM are too extensive and require too much expertise and resources to be applied for small water suppliers. For the few hundred small supplies in the Netherlands, a more basic WSP can play an important role in improving water safety for small systems. WHO identified an important role for WSP also for improving water safety for small systems. Valuable resources have been developed to support WSP implementation for small systems (WHO, 2017b). Nevertheless there remains a need for additional guidance materials and tools (WHO, 2017b).

In the highly professionalized and knowledge intensive context of the Dutch drinking water sector there is a clear notion that continuous improvements can always be made. With the current developments within the WHO and the European Union (WHO, 2015; EU, 2017), water quality monitoring is moving towards risk based surveillance. This development holds the promise of increasing cost-effectiveness of monitoring and surveillance efforts without jeopardizing public health. Therefore, it is crucial that the ten Dutch drinking water companies perform risk analysis to provide evidence for adapting testing parameters. As shown in this study, several risk assessments are indeed performed to identify possible (future) hazards. Based on these assessments the water quality monitoring plan can be adapted to become even more risk based.

5. Conclusions

Providing safe drinking water requires a proactive and preventative RA/RM approach. Whereas the WHO recommends a WSP as a RA/RM approach, Dutch drinking water companies use multiple RA/RM approaches, including different legally required RA/RMs. The six different RA/RM approaches are very specific and detailed, and focus on parts of the water supply. This study showed that these legal requirements, complemented by sector specific and company specific activities, cover all steps of the WSP. A long tradition of preventive risk management in the Netherlands, based on technical and theoretical insight, research and experience, has led to this combination of RA/RM approaches even before the WSP framework was developed. The six legally required RA/RM approaches provide advanced and detailed information on specific hazards and hazardous events in each part of the water supply chain. Therefore the outcomes need to be combined to provide information on all hazards and hazardous events from source to tap. Although the RA/RM in the Dutch drinking water sector is uniform, there are slight differences between individual companies. Using the various RA/RM approaches and subsequently combining and sharing all information (data) and systems is a challenge and a more harmonised approach could lead to improvements with respect to data sharing. The obligation of one WSP format seems to be too prescriptive for the current situation. However, generic arrangements for an integral RA/RM system would

help to develop a more uniform and transparent approach to further improve current practices.

Conflicts of interest

The authors declare no conflict of interest.

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Appendix A. Supplementary data

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