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Technical efficiency of existing risk reduction options for distribution of drinking water

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Summary

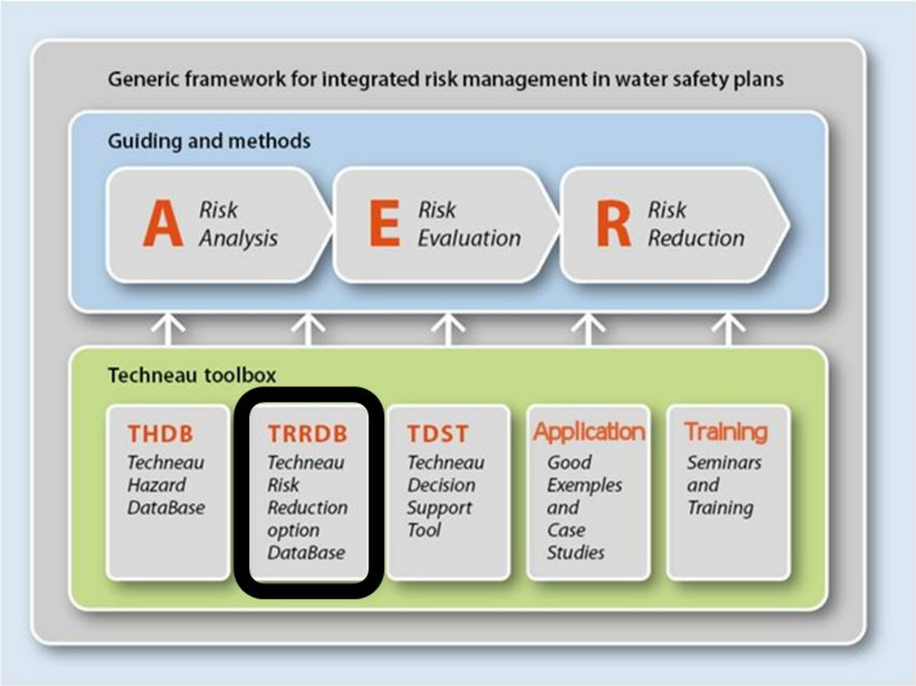
In the TECHNEAU project WA4, frameworks, methods and tools are presented for helping water companies with setting up a risk management system. In this report a number of Risk Reduction Options (RROs) are described for the distribution of drinking water. Within the framework adopted in this project, the supply system is subdivided into ten sub-systems (Beuken et al., 2008-a). In this report the scope of distribution of drinking water relates to reservoirs and pumps (Sub-system 7), the transport and distribution network (Sub-system 8) and internal piping (Sub-system 9). This report provides an overview of the different categories of RROs and how they are linked to each other. Examples on strategies and methods for a selected number of RROs are provided with references in the appendix. The list also includes some information on efficiency and costs of different barrier options.

This report provides some suggestions on how RROs for distribution can be selected in terms of strategy, possible methods, risk reduction efficiency and associated costs. It can therefore be used as a starting point to select RROs and some recommendations on literature for further reading.

Contents

1 Introduction

In the TECHNEAU project WA4, frameworks, methods and tools are presented for helping water companies with setting up a risk management system. In this report a number of Risk Reduction Options (RROs) are described for the distribution of drinking water. Within the framework adopted in this project, the supply system is subdivided into ten sub-systems (Beuken et al., 2008-a). In this report the scope of distribution of drinking water relates to reservoirs and pumps (Sub-system 7), the transport and distribution network (Sub-system 8) and internal piping (Sub-system 9). It should be read as an explanation to the corresponding sections in the database on Risk reduction options (TRRDB, see TECHNEAU, 2009) for the water supply system, developed within the TECHNEAU project as illustrated below.



1.1 Overview of suggested risk reduction options for drinking waters

The risk reduction options listed in the TECHNEAU risk reduction option database, TRRDB (TECHNEAU, 2009) are for each hazardous event specified in three categories. It should be noted that the characteristics of the Risk reduction options (RROs) differ significantly between these three categories:

- Control
- Education and Information
- Barriers

The connection between these categories of risk reduction options, in the context of water catchments is illustrated in Figure 1. The examples given for each level are further described below.

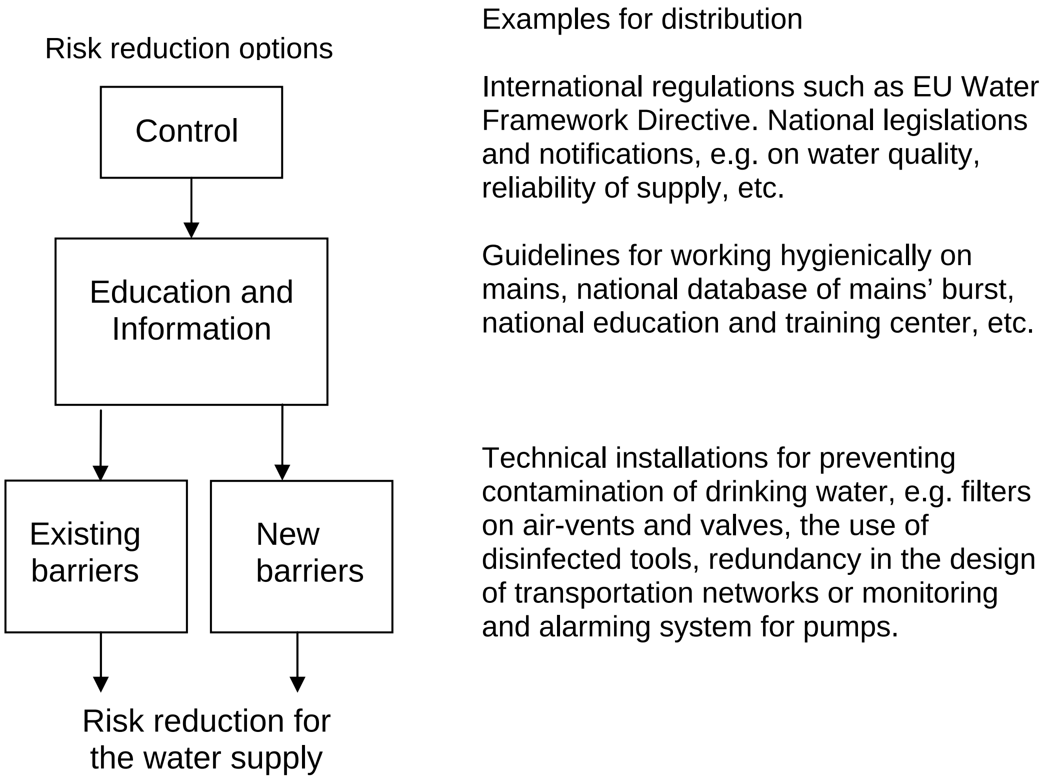


Figure 1. Overview of risk reduction options, including example

1.2 How to use this project

This report provides some suggestions on how RROs for the distribution of drinking water to customers can be selected in terms of strategy, possible methods, risk reduction efficiency and associated costs. It does not give a total description of RROs but it can be used as starting point to select RROs and to read more in the literature on different options. Some references are provided for each RRO. As each system will have their specific settings, there are various decision support tools available for making appropriate decisions (further described in the report D4.4.1, Decision support for risk management in drinking water supply- overview and framework).

2 Control options: regulations

Control options are systems for regulation, notifications or legislation on an international or a national level, according to the terminology in the TECHNEAU RRO database. For drinking water distribution these systems aim to control or prevent hazardous events. Control measures include e.g. the selection of the reservoir location, design and structure with basis on site vulnerability to natural hazards and soil geotechnical assessments (C7.1.1a) or washing and disinfecting of reservoirs before being put into service for the first time, and after being entered for cleaning, repair, or painting (C7.1.7a). Both references refer to TECHNEAU (2009). Other examples are the implementation of hygienic guidelines for mains repairs, including flushing and disinfection best practices (C8.1.7a).

As control options are not physical technical solutions but rather frameworks to control drinking water quality, the effect of risk reduction measures and the corresponding costs cannot be quantified. Risk reduction options in the control category therefore tend to be country-specific or at least EU-specific. Different frameworks are in use to protect and control drinking water from hazardous events in the European Union.

2.1 EU Council Directive 98/83/EC

At European level, the legislation for water quality intended for human consumption is approached in the Council directive 98/83/EC. The experience (resulting from Council Directive 80/778/EEC of 15 July 1980) showed that it is necessary to create an appropriately flexible and transparent legal framework for Member States to address failures to meet the standards. The set values for the microbiological and chemical parameters are to be found in the Annex I of the EU Council Directive 98/83/EC. Member States may set values for other additional parameters where that is deemed necessary for the purpose of ensuring the quality of the drinking water intended for human consumption. Since the preparation or distribution of water intended for human consumption may involve the use of certain substances or materials, rules are required to govern the use thereof in order to avoid possible harmful effects on human health. Accordingly to this directive, neither the domestic distribution system nor its maintenance may be the responsibility of the Member States. Domestic distribution system shall mean the pipes, fittings and appliances which are installed between the taps that are normally used for human consumption and the distribution network. Each Member State should establish monitoring programmes to check that water intended for human consumption meets the requirements of this Directive (minimum monitoring requirements). The methods used to analyze the quality of water intended for human consumption should be such as to ensure that the results obtained are reliable and comparable.

2.2 National regulations

In the Netherlands, the supply of drinking water lies within the influence area of the EU Council Directive 98/83/EC. The Dutch framework for the public drinking water supply is established in the Policy Plan for Drinking and Industry Water Supply.

In the Netherlands the supply of drinking water belongs to water companies, who are private ran but owned by public shareholders. Control of complying with set standards is a task of the government. The cooperation between these institutions is stimulated by the Ministry of Home Affairs as being essential for the protection of drinking water infrastructure. The drinking water companies must assure the continuity of the drinking water supply and prevent its failure. However local protection (governmental) institutions have to be prepared to intervene in case that calamity (disasters) will occur.
Not only national but also international collaboration programs are encouraged by the Ministry of Home Affairs; the introduction of a central network information system for European countries has being proposed.

Regarding the quality of drinking water there are two important law/rules worth to be mentioned:

a) *Water infrastructure law*- referring to the responsibility of the drinking water companies to provide with reliable quality of drinking water. It mentions the methods of water quality control as well.
b) *Water infrastructure rule*- referring to the maximum amount of specific chemical components allowed in the drinking water (under the responsibility of water infrastructure companies and owners of the water infrastructure installations). This rule is based on European Drinking Water directives (98/83/EC).

The two above mentioned rules/laws will be replaced in 2011 by the *Drinking water law* and *Drinking water rule*.

Lead pipes for drinking water supply were used before 1960. Due to the solubility of lead in water and the impossibility of its elimination by filtration or water boiling, the lead content in the drinking water can reach a dangerous level for the human health. Therefore, National government advises the remaining lead piping in houses to be replaced (not mandatory). All lead piping owned by water companies has already been replaced.

2.3 National standards for security of supply

2.3.1 *Framework to asses the reliability of supply.*

The Drinking water sector in the Netherlands has adopted (in 1994) a common framework (quantitative guideline) to assess the reliability of supply. This framework refers to the use of a hydraulic model of the water distribution network aiming to asses the supply capacity of the remaining supply system in case of (an element) breakdown. The introduction of a common framework was triggered by a series of factors:

- disasters of large public attention (Chernobyl and Sandoz);

- increasing supply zones due to merging water companies;
- a more critical attitude of customers towards supply interruption

The common Framework involves a Supply Plan set by the water company providing with information about the water quantity and pressure values in the supply system in three specific situations:
- **Normal working conditions** where the repair time of a failed (broken down) element doesn't exceed 24 hours.
- **Calamity** where the breakdown of a major component such as a burst of a major water main or breaking down of a pumping station (local scale) requires a repair time exceeding 24 hours.
- **Disaster** referring to events on a large scale such as break down of complete water production plant or the breakdown of multiple elements requiring a repair time longer than 24 hours.

The presumption of the reliability assessment is that every part of the system can fail, regardless of its probability of failure. For this reason, the assessment only focuses on the effects of the failure and can not be regarded as a full risk analyses. The criterion for evaluation is defined as: *in case of failure of one element of the drinking water supply system, the remaining capacity of supply to centres of demand should be at least 75% of the maximum daily demand.* A centre of demand is defined as a cluster of consumers equivalent to 2000 households. The reliability assessment was performed by means of a hydraulic network model assuming the direct dependency of the water supply on the increasing pressure.
The supply systems which do not fulfil the reliability criterion can be improved adequately through:
  - modifications of the redundant trunk mains;
  - constructions of connections to other supply zones;
  - increasing the capacity of treatment steps, pumps and reservoirs;
  - separation of production plants into parallel lines.

During the last 15 years, the water companies in the Netherlands have adopted the framework and have made improvements to the system of water supply where necessary. In conclusion:
- The framework on reliability and the corresponding quantitative assessment was successfully applied in the Dutch water companies providing with improvement of the supply system.
- Some larger incidents did occur in the Netherlands in the past 15 years, resulting in interruptions of supply for less than 24 hours.
- The framework for reliability is integrated in the new Drinking Water Act and it is a product of self-regulation of the drinking water sector.
- The framework can not be regarded as a full risk assessment but an (basic asset management) instrument to evaluate the robustness of the total supply system towards failure.
- Deviations from the framework can be approved, when necessary, by the Inspectorate.

- The reliability assessment can be done within the network calculation model ALEID (separate module) as well as by means of other modern commercial packages.

2.3.2 Risk assesment of mains at risky locations

The Dutch drinking water sector initiated a risk assessment method to evaluate the water mains at risky locations. The reason for this initiative was an incident taking place in the Netherlands (2004) where a dike of a main transportation canal was leaking and almost collapsed. The consequences of a possible burst would have been detrimental for the immediate surroundings. In general, the existence of leakage results in a deficient supply in terms of quantity and pressure and the water quality is affected by the introduction of pollutants.
This method describes the risk assessment of mains at risky location based on the likelihood of a pipe burst and possible consequences.
This framework consists of several steps for selecting the water mains, setting up the documentation about these mains, to estimate the risk and to define control measures. A computer model is used as a tool to determine the risk profile- the dependency between the pipe burst likelihood as function of consequences scale. The instrument also provides a list of possible control measures to minimize risk.
By the end of 2005, almost all water companies had made an inventory of water mains at risky locations introducing the necessary corrective measures (when needed).

3 Education and Information options

Education and Information activities are key components to bring out the message and contents of international and national legislation and regulations. These activities form the basis for decisions on technical installations (barriers) to mitigate specific hazardous events. Other directives from the EU relating to drinking water protection include: the Drinking Water Directive (EC 1998) and the Urban Waste Water Directive (EC 1991).
The objective of the **Drinking Water Directive** is to protect the health of the consumers in the European Union and to make sure the water is wholesome and clean. **Drinking Water Directive**:

- Sets quality standards for drinking water quality at the tap (microbiological, chemical and organoleptic parameters) and the general obligation that drinking water must be wholesome and clean.
- Obliges Member States to regular monitoring of drinking water quality and to provide to consumers adequate and up-to-date information on their drinking water quality.
- Member States may exempt water supplies serving less than 50 persons or providing less than 10 m^3 of drinking water per day as an average and water in food-processing undertakings where the quality of water cannot affect the wholesomeness of the foodstuff in its finished form.

The objective **Urban Waste Water Directive** is to protect the environment from the adverse effects of urban waste water discharges and discharges from certain industrial sectors and concerns the collection, treatment and discharge of: *Domestic waste water*, *Mixtures of waste water* and *Waste water from certain industrial sectors*.

Following the intentions in the WFD, everyone coming into contact with water issues should be involved. As the drinking water industry benefits from this work, they should be represented as an important organization in the water administration. Most of the involved parties are professional and industrial organizations. The involvement of the drinking water sector in the river basin management may result in the implementation of barriers that are beneficial for the water quality.

3.1 Education and information on planning of undeground infrastructure

An important RRO related to the distribution of drinking water relates to adopting good instruments for planning, protecting and exchanging information of underground infrastructure. In the Netherlands, GPKL (Gemeentelijk Platform Kabels en Leidingen) has the responsibility at municipal level for the intermediation between the underground infrastructure partners (cables and pipes). GPKL plays an important role in the introduction of new political developments such as the preparation for the "information-exchange of the underground networks". A second role of the GPKL is to collect and promote exchange of knowledge, information and experience related to the construction of the underground infrastructure. The National Government assigned GPKL as being responsible at a municipal level for these activities.

On 1 October 2008, the Law on “Information exchange of underground networks” (WION) was adopted. The purpose of this law was to reduce the number of digging accidents taking place in the Netherlands. The intermediation between the owners of the cables and piping networks and companies leading digging activities is done by the Land Register (officially designated by the Ministry of Economical Affairs). Land Register is an independent organization with experience in information supply and management of geo-information.

The Association of the Drinking Water Companies (VEWIN) emphasizes the importance of a “controlled” underground infrastructure. Due to the growing number of underground networks and the increasing need for compact constructions, issues concerning the available space could arise. Drinking water companies express their awareness regarding these aspects which could influence the integrity of the drinking water infrastructure. Therefore, respecting the technical requirements for the construction of the networks is essential in order to avoid the negative reciprocal influence between the different networks.

In the Netherlands, registration, updating and presentation of the data are required by laws. This is coordinated by the *Milieu management* law and *Calamity and Dangerous Accidents* law. Municipalities are responsible for the coordination of the “risk maps”. Since October 2008, the calamity type “Transportation of dangerous materials” was introduced on the “risk map”. Nowadays, the risk map contains 13 types of calamities including the “critical objects”. An example of a risk map is shown below where a calamity of the type “Transportation of dangerous materials” is considered.

The National Government is responsible for the registration and updating of the underground infrastructure. All relevant information of the piping systems regarding the ownership, the users group, type of pipe, technical parameters of the pipe, location and risk category is included in the risk maps data, see Figure 2 (also: www.risicokaart.nl). The risk maps are widely used mostly due to the existing information related to the piping infrastructure.

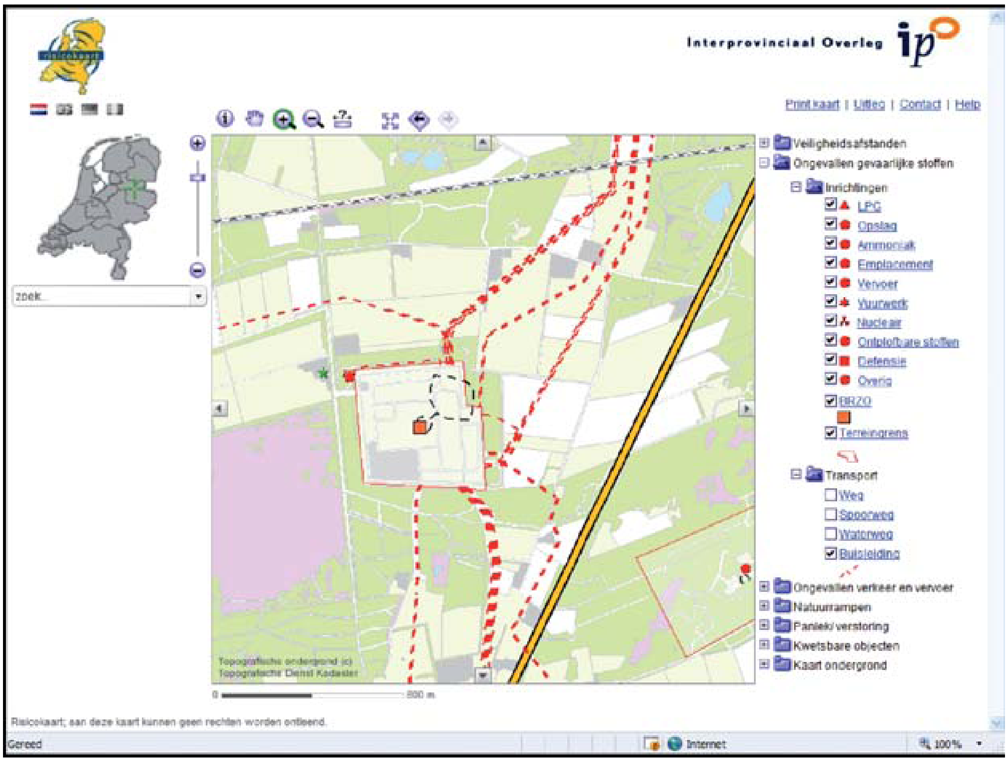


Figure 2Example of risk map on www.risicokaart.nl

3.2 National Benchmark in the Netherlands

The Association of Dutch Water Companies (VEWIN) represents the Dutch drinking water sector (ten water companies). VEWIN carries out a three yearly benchmark on the performance of the Dutch water companies. The benchmark covers the topics water quality, quality of service, environment and finances & efficiency. The aim of the benchmark study is to create transparency in the operating results and to serve as a tool for further improving the water companies' business processes.

The report 'Reflections on Performance 2009' (VEWIN, 2010) is the fifth benchmarking study in the Dutch drinking water industry. An example of the figures presented in this report is the performance indicator customer interruption. A distinction was made between the consequences of disruptions (unscheduled interruptions) and regular maintenance (scheduled interruptions).
The average duration of unscheduled disruptions is 7:35 minutes per year. This is an increase of 32 % compared with 2006. The duration of disruptions varies between 1:58 and 12:49 minutes per connection per year, see Figure 3. The duration of interruptions for regular maintenance (scheduled) averages 9:24 minutes per year per connection and varies between 4:49 and 22:02 minutes, see Figure 4. This is an increase of 19% compared with 2006. About 20% of the disruptions are caused by third parties, e.g. damage to the network caused by digging.

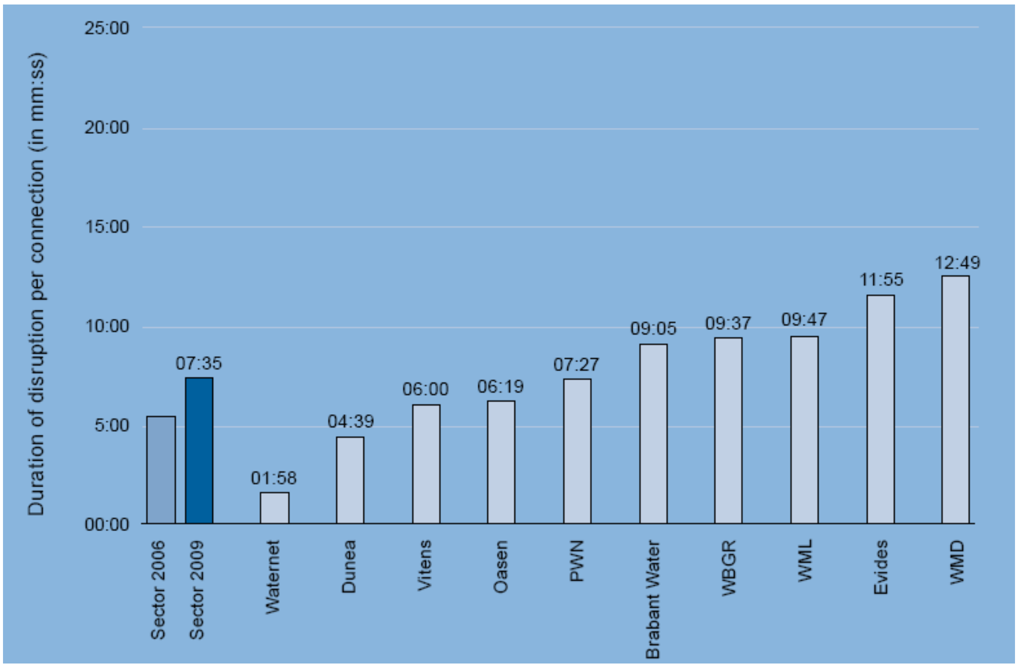


Figure 3. Average duration of unscheduled disruptions for maintenance in 2009

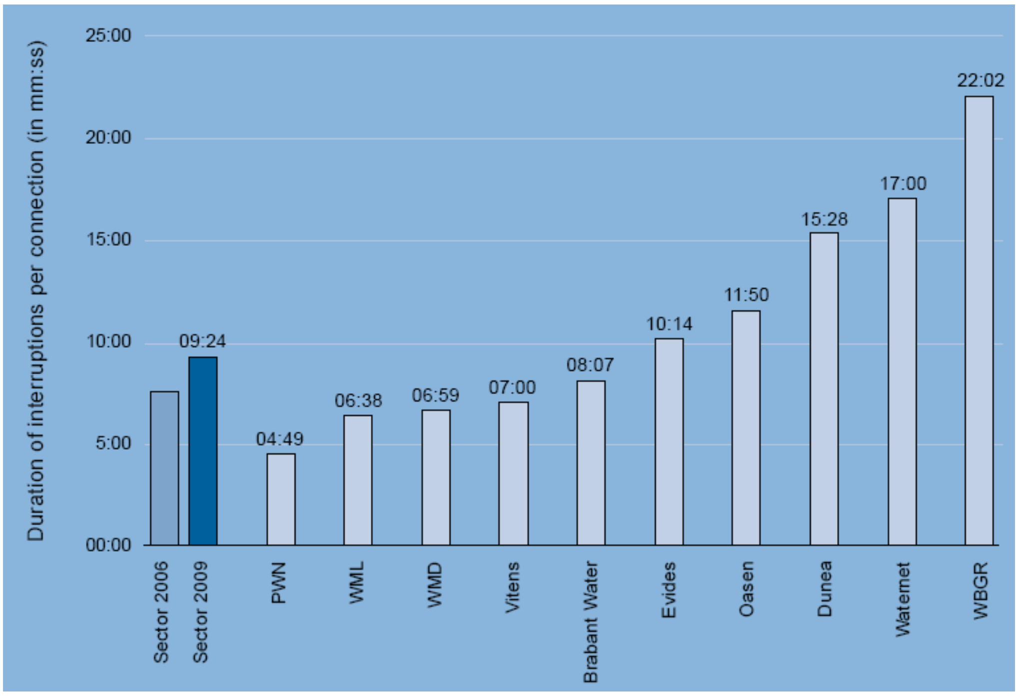


Figure 4. Average duration of scheduled disruptions in 2009

The figures presented in Figure 3 and Figure 4 make part of the indicator measuring the continuity of supply of drinking water: Substandard Supply Minutes (SSM). SSM is defined as measure of insufficiency regarding water quality and quantity (low pressure or interruption of the water supply). SSM gives an insight in the factors playing an important role to the total interruption of supply and quality of water and thus supporting asset management. Both scheduled and un-scheduled interruptions are considered (failures, repair and replacements). Dutch water companies evaluate all activities undertaken in the network resulting in interruption of supply with the aim to improve operations, with the aim to decrease the number of interruption, shorten the duration of an interruption or to affect fewer customers due to an interruption.

4 Barrier options: technical efficiency and costs

This category of risk reduction options refers to technical improvements in existing pumping stations, water distribution systems and in in-house connections, such as redundant pumps, sufficient water pressure to prevent the ingress of pollutants and non-return valves to prevent backflow. While most of the RROs in the categories *Control* and *Education and Information* are designed to lower the probability (P) of the hazardous event to occur, the RROs in the Barrier category also includes options to lower the consequence (C) of the event. For instance probability of damage or destruction of a reservoir due to natural disasters (7.1.1) can be reduced by making a vulnerability assessment which could result in effective and location specific risk reduction options, like the displacement of the reservoir or constructional reinforcements (B7.1.1.a). The consequences of this event could be reduced making a emergency response plan, which could result in options like preparedness training, additional metering, communication plans or back-up capacity (B7.1.1.b).

A list of the risk reduction options in the TRRDB related to barriers for reservoirs, pumping stations, distribution network and in-house piping is provided in Appendix A. It must borne in mind that barriers for controlling hazardous events must be appropriate for the specific water system and local circumstances must be taken into account, such as physical limitations in the infrastructure, relevant pollutants, human activities, etc. Of these examples also some guidelines are given on their respective effectiveness and the costs.

The descriptions applied in Appendix A to define the **effectiveness** of the options are qualitative and subjective. Given the large impact of local circumstances and the large range of different measures to enforce the options, it is not possible to provide precise and quantitative descriptions. For measures of uniformity, where possible the following descriptions are applied at the database:

- Absolutely effective, e.g. eliminating plumbosolvency by replacing all lead pipes and solders;
- probably effective: proven technology, the option will probably result in a considerable reduction of the probability of the consequences, e.g. mitigate plumbosolvency by amending the water pH and composition
- potentially effective: options that could be effective, but only when considerable constraints (technological, operational, etc) are met, e.g. eliminating plumbosolvency by inserting internal lining.

As defined before for the effectiveness of different risk reduction options, it is also not possible to provide accurate costs figures. In the database presented in Appendix A, a four-scale description of costs is applied for describing the **magnitude of costs** related to investments (CAPEX) or operation and maintenance (OPEX). The cost level indicated in the database is relative to the expenditure for rebuilding of the element described, e.g. a reservoir or a house connection. For the distribution network this is to be interpreted differently, as the total costs of the network are extremely high. In this case the costs are relative to a main of a length of one km with the same characteristics. In Table 1 the definition of costs is illustrated.

Table 1 Definition of the costs as applied in the barrier database

Element	
· Investment	Relative to the expenditure for rebuilding
o very high costs:	> 100%
o high costs:	25 – 100%
o moderate costs:	5 – 25%
o low costs:	< 5%
· Operation and maintenance	Relative to the average costs for operation and maintenance
o very high costs:	> 100%
o high costs:	25 – 100%
o moderate costs:	5 – 25%
o low costs:	< 5%
Network	
· Investment	Relative to the expenditure for rebuilding a main with the same characteristics of 1 km length
o very high costs:	> 100%
o high costs:	25 – 100%
o moderate costs:	5 – 25%
o low costs:	< 5%
· Operation and maintenance	Relative to the average costs for operation and maintenance of a main with the same characteristics of 1 km length
o very high costs:	> 100%
o high costs:	25 – 100%
o moderate costs:	5 – 25%
o low costs:	< 5%

4.1 Tools for assesing the efficiency of risk reduction measures

An example of a tool for assessing the efficiency of risk reduction is CAVLAR. CAVLAR acronym for Criticality Analysis Valve Locations And Reliability, is developed by KWR and helps water companies to make a criticality analysis of the network, taking into account the location and performance of valves (Beuken et al., 2008-b). The majority of the input for CAVLAR consists of a detailed hydraulic model. For first analysis a valve section diagram is automatically generated. In this section diagram, sections of a network are displayed as nodes and the valves are displayed as connecting lines (see Figure 5). With a valve section diagram, it is possible to quickly find obvious critical sections; e.g. because of the high number of connections or valves in a section, or because a section has an obvious transportation function.

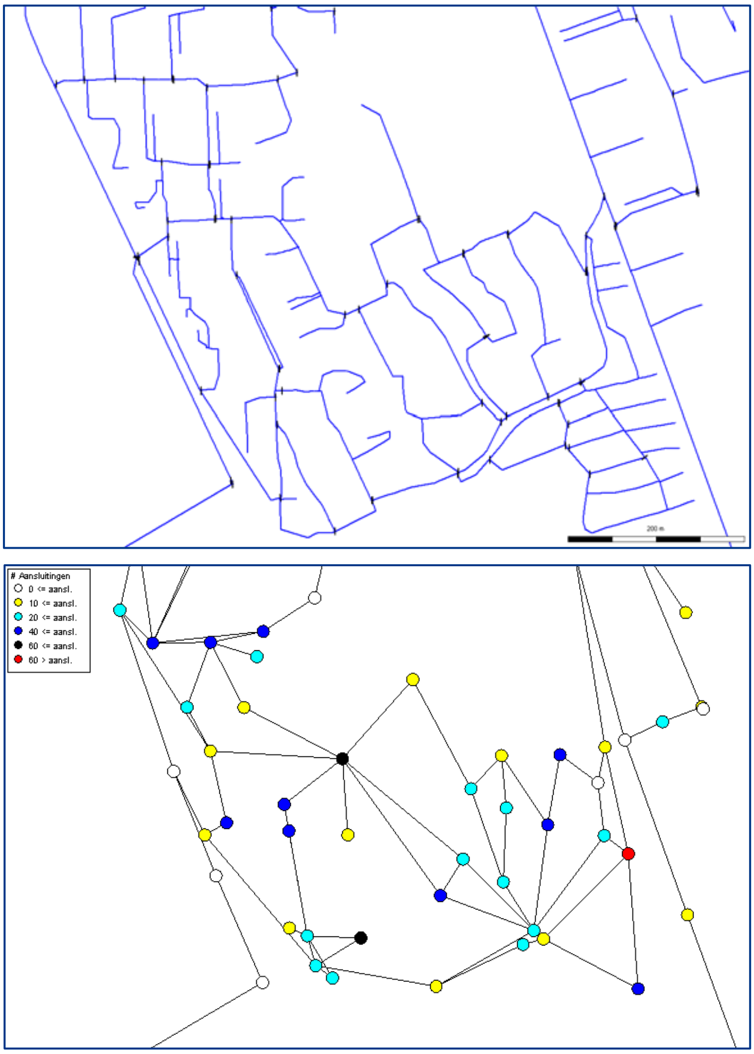


Figure 5. Example of a network model (left) schematized as a valve section diagram (right). In the valve section diagram nodes are sections with a colour indicating the number of connections and lines are valves.

The CAVLAR software divides the network into valve sections and simulates a pipe burst in each section. As a next step isolation for repair is simulated by closing the valves. Whether a valve closes or not depends on the reliability of the valve. If a valve does not close, the connected valve section is also involved in the incident, and the connections are added to the impact.

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Appendix A: Strategy, effect and associated costs for RRO by barriers

<u>7. Technical efficiency of existing risk reduction options in reservoirs and pumps</u>
The risk reduction options/barriers correspond to the items in the TRRDB, subsystem 7.
Type - type of option: P = probability reducing option, C = consequence reducing option

Hazardous event (ref. from THDB)		Risk reduction option/Barriers			Strategy and some examples on methods from the literature			Costs	
(no.)	**(description)**	**Ref.**	**Option**	**Type**	**Strategy (reference)**	**Method (reference)**	**Effectiveness**	**Investment**	**Operation and maintenance**
7.1.1	Damage or destruction of reservoir due to natural disasters (earthquakes, hurricanes, floods, landslides, volcanic eruptions)	B7.1.1a	Emergency Response Plan. Reservoir automatically insulated by shut-off valves designed to react in the event of natural disasters. Sufficient system redundancy is required.	C	Disaster vulnerability assessments related to local circumstances for tank location, design, structure and components (WHO, 2002).	Assessment and implementation of a vulnerability assessment (PAHO, 1998; WHO, 2002).	Vulnerability Assessment reduces probability of hazardous event occurrence. Effect highly dependant of disaster type and intensity and response preparedness.	Low costs for assessment and planning. Costs for implementing measures vary from low (e.g. new valves) to very high (e.g. additional reservoir).	Emergency Response Plan maintenance has relatively low costs in updating and personnel training. Costs for implementation of measures can vary from low to very high.
		B7.1.1b	Emergency Response Plan. Reservoir automatically insulated by shut-off valves designed to react in the event of natural disasters. Sufficient system redundancy is required.	P	Enforcement of Emergency Response Plan (AWWA, 2001).	Assessment and implementation of an Emergency Response Plan (AWWA, 2001). Possible measures: preparedness training, additional metering, communication plan, back-up capacity, etc	Emergency Response Plan identifies activities minimizing (major) consequences. Effect depending on kind of disaster and kind of activity.	Vulnerability Assessment and Emergency Response Plan implementation have moderate costs. Costs to implement redundancy may be moderate (e.g., new valves) to high (e.g., new mains).	Emergency Response Plan maintenance has relatively low costs in updating and personnel training. Costs for implementation of measures can vary from low to high.
7.1.2	Damage or destruction of reservoir due to human-caused accidents (car or plane collision, landslides caused by reservoir leakage or nearby excavation)	B7.1.2a	Emergency Response Plan. Reservoir automatically insulated by shut-off valves designed to react in the event its destruction. System redundancy.	C	Enforcement of Emergency Response Plan (AWWA, 2001). Tank location, design, structure and components based on locals disaster vulnerability assessments (WHO, 2002).	Emergency Response Plan (AWWA, 2001). Vulnerability assessments (PAHO, 1998; WHO, 2002).	Emergency Response Plan minimizes major consequences. Vulnerability Assessment reduces probability of hazardous event occurrence. Effect highly dependant of disaster type and intensity and response preparedness.	Vulnerability Assessment and Emergency Response Plan implementation have moderate costs. Tank location, design, construction and redundancy costs are site specific. Costs to implement redundancy may be moderate (e.g., new valves) to high (e.g., new mains).	Emergency Response Plan maintenance has relatively low costs in updating and personnel training.

Hazardous event (ref. from THDB)		Risk reduction option/Barriers			Strategy and some examples on methods from the literature			Costs	
(no.)	**(description)**	**Ref.**	**Option**	**Type**	**Strategy (reference)**	**Method (reference)**	**Effectiveness**	**Investment**	**Operation and maintenance**
		B7.1.2b	Emergency Response Plan. Reservoir automatically insulated by shut-off valves designed to react in the event its destruction. System redundancy.	C	Enforcement of Emergency Response Plan (AWWA, 2001). Tank location, design, structure and components based on locals disaster vulnerability assessments (WHO, 2002).	Emergency Response Plan (AWWA, 2001). Vulnerability assessments (PAHO, 1998; WHO, 2002).	Emergency Response Plan minimizes major consequences. Vulnerability Assessment reduces probability of hazardous event occurrence. Effect highly dependant of disaster type and intensity and response preparedness.	Vulnerability Assessment and Emergency Response Plan implementation have moderate costs. Tank location, design, construction and redundancy costs are site specific. Costs to implement redundancy may be moderate (e.g., new valves) to high (e.g., new mains).	Emergency Response Plan maintenance has relatively low costs in updating and personnel training.
7.1.3	Intentional damage or destruction of reservoir (terrorism, sabotage, vandalism, arson)	B7.1.3a	Enhanced security by monitoring/controlling and eliminating unauthorized access to the site and ensuring access barriers.	P	Access to site restricted and efficaciously controlled (AWWA, 2001).	Access efficiently controlled by physical barriers (fences, locks, CCTV) and monitoring (AWWA, 2001).	Incident probability highly reduced (AWWA, 2001).	Access barriers and monitoring equipment (e.g., video cameras, locks, fences) of relatively low cost.	Staff and maintenance of vigilance network costs are relatively low .
		B7.1.3b	Enhanced security by monitoring/controlling and eliminating unauthorized access to the site and ensuring access barriers.	C	Enforcement of Emergency Response Plan (AWWA, 2001).	Assessment and implementation of an Emergency Response Plan (AWWA, 2001). Possible measures: preparedness training, additional metering, communication plan, back-up capacity, etc	Emergency Response Plan identifies activities minimizing (major) consequences. Effect depending on kind of disaster and kind of activity.	Vulnerability Assessment and Emergency Response Plan implementation have moderate costs.	Emergency Response Plan maintenance has relatively low costs in updating and personnel training. Costs for implementation of measures can vary from low to high.
7.1.4	Reservoir structure damage due to excessive internal pressure build-up	B7.1.4a	Emergency Response Plan. Reservoir automatically insulated by shut-off valves designed to react in the event its destruction. Redundancy in reservoir venting.	P/C	Enforcement of Emergency Response Plan (ERP) (AWWA, 2001). Implementation of sound inspection / maintenance of reservoir pressure related components (Vitanage et al., 2004).	ERP (AWWA, 2001). Rehabilitation planning (RP) (Vitanage et al., 2004).	ERP minimizes major consequences. RP may reduce probability of the hazardous event efficiently.	ERP and RP implementation have moderate costs.	ERP and RP maintenance have relatively low costs in updating and personnel training.

Hazardous event (ref. from THDB)		Risk reduction option/Barriers			Strategy and some examples on methods from the literature			Costs	
(no.)	**(description)**	**Ref.**	**Option**	**Type**	**Strategy (reference)**	**Method (reference)**	**Effectiveness**	**Investment**	**Operation and maintenance**
7.1.5	Wrong water level metering or data processing system malfunctioning	B7.1.5a	Continuous monitoring and automatic valve control of the pressure of the water entering the network by using SCADA or equivalent systems.	P/C	Implementation of sound inspection / calibration /maintenance of reservoir pressure related components (Vitanage et al., 2004).	Maintenance and survey of distribution systems (Vitanage et al., 2004).	Potential effective.	Implementation has low to moderate costs.	Maintenance has relatively low costs in updating and personnel training.
7.1.6	Intentional contamination of the network water (terrorism, sabotage, vandalism, arson)	B7.1.6a	Enhanced security by monitoring/controlling and eliminating unauthorized access to the site and ensuring access barriers.	P/C	Access to site restricted and efficaciously controlled (AWWA, 2001).	Access efficiently controlled by physical barriers and monitoring (AWWA, 2001).	Incident probability highly reduced (AWWA, 2001).	Access monitoring equipment (e.g., video cameras) of low cost	Staff and maintenance of vigilance network costs are relatively low .
		B7.1.6b	Vents and overflow pipes provided with inflow preventing devices. Plan and practice emergency response procedures.	P	Access to site restricted and efficaciously controlled (AWWA, 2001).	Access efficiently controlled by physical barriers and monitoring (AWWA, 2001).	Incident probability highly reduced (AWWA, 2001).	Vents and overflow pipes provided with inflow preventing devices of low cost.	Maintenance of inflow preventing devices of low cost.
7.1.7	Introduction of contaminants by improper use of material or operational errors	B7.1.7a	Enforcement of legislation on materials and compounds in contact with water for human consumption	P	Prevent the use of improper materials in reservoirs construction and repairing.	Use of the products complying with National Acceptance Scheme for products in contact with drinking water.	High efficiency is expected from these risk reduction options.	Low cost.	
		B7.1.7b	Monitor VOC in the water of reservoirs which repair involved the use of volatile organic compounds containing products, before putting reservoir in service	P	Monitor maintenance & repair practices adequacy and safety by controlling potential contamination of reservoir water during repairs.	Flushing and monitoring water for VOC prior to put reservoir in service (USEPA, 2002; Ainsworth and Holt, 2004)	Generally best practices prevent risks efficiently (USEPA, 2002; Ainsworth and Holt, 2004).	Relatively low costs for personnel training and best practices implementation.	Relatively low costs for personnel training and best practices implementation.

Hazardous event (ref. from THDB)		Risk reduction option/Barriers			Strategy and some examples on methods from the literature			Costs	
(no.)	**(description)**	**Ref.**	**Option**	**Type**	**Strategy (reference)**	**Method (reference)**	**Effectiveness**	**Investment**	**Operation and maintenance**
		B7.1.7c	Checking of the chemical/microbiological quality of the water before putting reservoirs in service	P	Monitor maintenance & repair practices adequacy and safety by controlling potential contamination of reservoir water during repairs.	Flushing and monitoring the chemical and microbiological quality of water prior to put reservoir in service (USEPA, 2002; Ainsworth and David Holt, 2004)	Generally best practices prevent risks efficiently (USEPA, 2002; Ainsworth and David Holt, 2004).	Relatively low costs for personnel training and best practices implementation.	Relatively low costs for personnel training and best practices maintenance.
		B7.1.7d	Reservoir isolation valves closed until maintenance /repair is finished and water safety is confirmed by analysis	P	Monitor maintenance & repair practices adequacy and safety by controlling potential contamination of reservoir water during repairs.	Flushing and monitoring the chemical and microbiological quality of water prior to put reservoir in service (USEPA, 2002; Ainsworth and David Holt, 2004)	Generally best practices prevent risks efficiently (USEPA, 2002; Ainsworth and David Holt, 2004).	Relatively low costs for personnel training and best practices implementation.	Relatively low costs for personnel training and best practices maintenance.
7.1.8	Poor hygiene during reservoir construction, repair or cleaning	B7.1.8a	Checking of the chemical/microbiological quality of the water before putting reservoirs in service	C	Monitor maintenance & repair practices adequacy and safety by controlling potential contamination of reservoir water during repairs.	Flushing and monitoring the chemical and microbiological quality of water prior to put reservoir in service, disinfection of all equipment potentially in contact with drinking water (USEPA, 2002; Ainsworth and David Holt, 2004).	Generally best practices prevent risks efficiently (USEPA, 2002; Ainsworth and David Holt, 2004).	Relatively low costs for personnel training and best practices implementation.	Relatively low costs for personnel training and best practices maintenance.
		C7.1.8b	Medical control/licensing of the construction/repair/cleaning personnel	P	Prevent waterborne transmissible-disease carriers to come into contact with the distribution system of potable water supplies (Ainsworth and David Holt, 2004).	A medical officer should review the suitability of individuals for restricted operations at regular intervals (Ainsworth and David Holt, 2004).	Regular personnel-health checks prevents most risks effectively.	No investment costs are required	Relatively low costs for personnel health checks.

Hazardous event (ref. from THDB)		Risk reduction option/Barriers			Strategy and some examples on methods from the literature			Costs	
(no.)	(description)	Ref.	Option	Type	Strategy (reference)	Method (reference)	Effectiveness	Investment	Operation and maintenance
7.1.9	Intrusion of contaminants (e.g., bird and animal faeces), dust or vermin through improperly sealed access openings or hatches, vents and overflow pipes	B7.1.9a	Vent and overflow pipes with screens and designed and provided with devices so as inflow is prevented.	P	Proper design and maintenance of reservoirs provide a barrier to contaminants entrance (USEPA, 2002).	Verification/ inspection and proper design/maintenance /rehabilitation of components with access to reservoir (USEPA, 2002).	Provided the correct design/maintenance/ rehabilitation, an efficient risk reduction is achieved (USEPA, 2002).	Proper tank design does not necessarily imply significant increases in construction costs.	Inspection and maintenance costs are generally low. Rehabilitation costs may be low to moderate.
		B7.1.9b	Effectively sealed access openings or hatches and efficiently screened vents and overflow pipes (see B7.1.9.a)	P/C	Proper design and maintenance of reservoirs provide a barrier to contaminants entrance (USEPA, 2002).	Verification/ inspection and proper design/maintenance /rehabilitation of components with access to reservoir (USEPA, 2002).	Provided the correct design/maintenance/ rehabilitation, effective risk reduction is achieved (USEPA, 2002).	Proper tank design does not necessarily imply significant increases in construction costs.	Inspection and maintenance costs are generally low. Rehabilitation costs may be low to moderate.
7.1.10	Intrusion of contaminants through cracks in the reservoir roof	B7.1.10a	Implement best practice protocols for reservoir design, inspection and maintenance, including reservoir roof condition assessment and maintenance	P	Proper design and maintenance of reservoirs provide a barrier to contaminants entrance (USEPA, 2002).	Verification/ inspection and proper design/maintenance /rehabilitation of components with access to reservoir (USEPA, 2002).	Provided the correct design/maintenance/ rehabilitation, effective risk reduction is achieved (USEPA, 2002).	Proper tank design does not necessarily imply significant increases in construction costs.	Inspection and maintenance costs are generally low. Rehabilitation costs may be low to moderate.
7.1.11	Intrusion of contaminants through cracks in the reservoir walls or floor	B7.1.11a	Perform site assessment, covering potential (e.g., sewers, service station tanks) and actual (e.g., analysis of soil for pollutants) sources of contaminants, preliminary to selecting buried-reservoir location	P	Proper design and maintenance of reservoirs provide a barrier to contaminants entrance (USEPA, 2002).	Verification/ inspection and proper design/maintenance /rehabilitation of components with access to reservoir (USEPA, 2002).	Provided the correct design/maintenance/ rehabilitation, effective risk reduction is achieved (USEPA, 2002).	Proper tank design does not necessarily imply significant increases in construction costs.	Inspection and maintenance costs are generally low. Rehabilitation costs may be low to moderate.

Hazardous event (ref. from THDB)		Risk reduction option/Barriers			Strategy and some examples on methods from the literature			Costs	
(no.)	**(description)**	**Ref.**	**Option**	**Type**	**Strategy (reference)**	**Method (reference)**	**Effectiveness**	**Investment**	**Operation and maintenance**
		B7.1.11b	Monitoring of the chemical and microbiological quality of the outlet water	C	Regular monitoring of the chemical and microbiological quality of the water leaving the reservoir to assure that no contaminants enter the distribution system (USEPA, 2002).	Programmed monitoring of the inflowing/out flowing water (USEPA, 2002).	Generally, a reliable risk reduction is achieved (USEPA, 2002). Generally, risk reduction is reliable (USEPA, 2002).	Costs of online monitoring devices may be low to moderate.	Sampling and analysis, and monitoring equipment operation and maintenance are of relatively low cost.
7.1.12	Aging of water due to low turnover rates or uneven hydraulic mixing	B7.1.12a	Implement best practice protocols for reservoir design (to prevent stagnant areas) and operation (to promote minimum required storage volumes).	P	Proper design and maintenance of reservoirs provide a barrier to contaminants entrance (USEPA, 2002).	Verification/ inspection and proper design/maintenance /rehabilitation of components with access to reservoir (USEPA, 2002).	Provided the correct design/maintenance/ rehabilitation, an efficient risk reduction is achieved (USEPA, 2002).	Proper tank design does not necessarily imply significant increases in construction costs.	Hydraulic calculations are required to define the minimum required volume. Costs can be moderate.
		B7.1.12b	Monitoring of reservoir input/output water flow and output water disinfectant residual and microbiological quality	C	Monitoring of the chemical and microbiological quality of the outlet water to assure that no contaminants enter the distribution system (USEPA, 2002).	Programmed monitoring of the inflowing/out flowing water (USEPA, 2002).	Generally, a reliable risk reduction is achieved (USEPA, 2002). Generally, risk reduction is reliable (USEPA, 2002).	Costs of online monitoring devices may be low to moderate.	Sampling and analysis, and monitoring equipment operation and maintenance are of relatively low cost.
		B7.1.12c	Flow, disinfectant residual and microbiological quality monitoring of representative samples of the water leaving the reservoir or each separate compartment of a multi-tank system	C	Monitoring of the chemical and microbiological quality of the outlet water to assure that no contaminants enter the distribution system (USEPA, 2002).	Programmed monitoring of the inflowing/out flowing water (USEPA, 2002).	Generally, a reliable risk reduction is achieved (USEPA, 2002). Generally, risk reduction is reliable (USEPA, 2002).	Costs of online monitoring devices may be low to moderate.	Sampling and analysis, and monitoring equipment operation and maintenance are of relatively low cost.

Hazardous event (ref. from THDB)		Risk reduction option/Barriers			Strategy and some examples on methods from the literature			Costs	
(no.)	**(description)**	**Ref.**	**Option**	**Type**	**Strategy (reference)**	**Method (reference)**	**Effectiveness**	**Investment**	**Operation and maintenance**
7.1.13	Excessive accumulation of sediments on the reservoirs floor	B7.1.13a	Turbidity monitoring and/or particle counting in the treatment plant output water	C	Monitoring of the chemical and microbiological quality of the outlet water to assure that no contaminants enter the distribution system (USEPA, 2002).	Programmed monitoring of the inflowing/out flowing water (USEPA, 2002).	Generally, a reliable risk reduction is achieved (USEPA, 2002). Generally, risk reduction is reliable (USEPA, 2002).	Costs of online monitoring devices may be low to moderate.	Sampling and analysis, and monitoring equipment operation and maintenance are of relatively low cost.
		B7.1.13b	Reservoir best – practice maintenance, comprising periodical cleaning/disinfection of the reservoir	P	Use of proper procedures and products (AWWA, 2002).	Verification/ inspection of the cleaned reservoir outlet water safety (USEPA, 2002).	Generally effective risk reduction is achieved (USEPA, 2002).	None	Relatively low costs for personnel and materials
7.1.14	Excessive biofilm accumulation on tank walls	B7.1.14a	Monitoring and control of treated water AOC/BOC	P	Manage the potential for biofilm development on tanks walls (USEPA, 2002).	Keeping water AOC below 100 µg / L prevents excessive microbial regrowth (LeChevallier et al., 1987).	Efficiency highly dependent on water specific characteristics.	Minimizing / removing AOC at treatment may require moderate to high investment costs with equipment.	Monitoring AOC has relatively low costs.
		B7.1.14b	Cleaning of the reservoir wall	C	Proper design and maintenance of reservoirs provide a barrier to contaminants entrance (USEPA, 2002).	Verification/ inspection and proper design/maintenance /rehabilitation of components with access to reservoir (USEPA, 2002).	Provided the correct design/maintenance/ rehabilitation, an efficient risk reduction is achieved (USEPA, 2002).	None	Costs for cleaning are relatively moderate
		B7.1.14c	Monitoring of the microbiological quality of reservoir outlet water	C	Monitoring of the microbiological quality of the outlet water to assure that no contaminants enter the distribution system (USEPA, 2002).	Programmed monitoring of the inflowing/out flowing water (USEPA, 2002).	Generally, a reliable risk reduction is achieved (USEPA, 2002).	Costs of online monitoring devices may be low to moderate.	Sampling and analysis, and monitoring equipment operation and maintenance are of relatively low cost.
7.2 Pumping station									

Hazardous event (ref. from THDB)		Risk reduction option/Barriers			Strategy and some examples on methods from the literature			Costs	
(no.)	**(description)**	**Ref.**	**Option**	**Type**	**Strategy (reference)**	**Method (reference)**	**Effectiveness**	**Investment**	**Operation and maintenance**
7.2.1	Destruction of pumping station due to natural disasters (earthquakes, hurricanes, floods, landslides, volcanic eruptions)	B7.2.1a	Emergency Response Plan. System redundancy.	P	Enforcement of Emergency Response Plan (AWWA, 2001). Pumping station location, design, structure and components based on locals disaster vulnerability assessments (WHO, 2002).	Emergency Response Plan (AWWA, 2001). Vulnerability assessments (PAHO, 1998; WHO, 2002).	Emergency Response Plan minimizes major consequences. Vulnerability Assessment reduces probability of hazardous event occurrence. Options efficiency highly dependant of disaster type and intensity and response preparedness.	Vulnerability Assessment and Emergency Response Plan implementation have moderate costs. Pumping station , design, construction and redundancy costs are site specific. Costs to implement redundancy may be moderate (e.g., new valves) to high (e.g., new mains).	Emergency Response Plan maintenance has relatively low costs in updating and personnel training.
7.2.2	Damage or destruction of pumping station due to human-caused accidents (car, truck or aircraft collision, landslides caused by leakage or nearby excavation)	B7.2.2a	Emergency Response Plan. System redundancy.	P	Enforcement of Emergency Response Plan (AWWA, 2001). Pumping station, design, structure and components based on locals disaster vulnerability assessments (WHO, 2002).	Emergency Response Plan (AWWA, 2001). Vulnerability assessments (PAHO, 1998; WHO, 2002).	Emergency Response Plan minimizes major consequences. Vulnerability Assessment reduces probability of hazardous event occurrence. Options efficiency highly dependant of disaster type and intensity and response preparedness.	Vulnerability Assessment and Emergency Response Plan implementation have moderate costs. Pumping station location, design, construction and redundancy costs are site specific. Costs to implement redundancy may be moderate (e.g., new valves) to high (e.g., new mains).	Emergency Response Plan maintenance has relatively low costs in updating and personnel training.
		B7.2.2b	Emergency Response Plan. System redundancy.	P	Enforcement of Emergency Response Plan (AWWA, 2001). Pumping station, design, structure and components based on locals disaster vulnerability assessments (WHO, 2002).	Emergency Response Plan (AWWA, 2001). Vulnerability assessments (PAHO, 1998; WHO, 2002).	Emergency Response Plan minimizes major consequences. Vulnerability Assessment reduces probability of hazardous event occurrence. Options efficiency highly dependant of disaster type and intensity and response preparedness.	Vulnerability Assessment and Emergency Response Plan implementation have moderate costs. Tank location, design, construction and redundancy costs are site specific. Costs to implement redundancy may be moderate (e.g., new valves) to high (e.g., new mains).	Emergency Response Plan maintenance has relatively low costs in updating and personnel training.

Hazardous event (ref. from THDB)		Risk reduction option/Barriers			Strategy and some examples on methods from the literature			Costs	
(no.)	(description)	Ref.	Option	Type	Strategy (reference)	Method (reference)	Effectiveness	Investment	Operation and maintenance
7.2.3	Intentional damage or destruction of pumping station (terrorism, sabotage, vandalism, arson)	B7.2.3a	Enhanced security by monitoring/controlling and eliminating unauthorized access to the site and ensuring access barriers. System redundancy	P	Access to site restricted and efficaciously controlled (AWWA, 2001).	Access efficiently controlled by physical barriers and monitoring (AWWA, 2001).	Incident probability highly reduced (AWWA, 2001).	Access monitoring equipment (e.g., video cameras) of low cost	Staff and maintenance of vigilance network costs are relatively low .
7.2.4	Damage or destruction of network pumps and pipes due to water hammer	B7.2.4a	Checking of long sections of mains with higher velocities for transient conditions. Prevent the development of destructive surge pressures by having pump control valves, surge anticipation valves, surge tanks, vacuum relief valves, regulated air release valves, optimizing main size and alignment, etc.	C	Prevent the development of destructive surge pressures by proper design, equipment and operation of the system (Chambers et al., 2004).	Make a surge analysis of the distribution system to find critical sectors and, accordingly, install anti surge equipment. Implement good practices for pump and valve manoeuvring (Chambers et al., 2004).	Although dependent on the conditions of each system, destructive surge pressures are generally prevented effectively.	Even if generally of moderately cost, required equipment investment depends on the existing conditions. Operational good practices implementation and personnel training have relatively low costs.	No specific costs are added to those required for routine operation and maintenance of the system.
7.2.5	Pump malfunctioning/failure	B7.2.5a	System redundancy. Availability of backup pumps. Use of SCADA output data on pump and reservoir operational status	P	Minimize malfunction/failure events by implementing proper inspection and maintenance of pump and gauges functioning and condition. Use of SCADA or equivalent systems to continuously check/control pump operation/network pressures. Assure redundancy.	Best practices programmed monitoring and maintenance of pumps functioning and condition.	While dependant on the conditions of each system, risk reduction efficiency is high, particularly if pump backups and/or system redundancy are assured.	Required equipment investment costs are site specific. It may be moderate to high if pump backups need to be implemented.	No specific costs are added to those required for routine operation and maintenance of the system.

Hazardous event (ref. from THDB)		Risk reduction option/Barriers			Strategy and some examples on methods from the literature			Costs	
(no.)	**(description)**	**Ref.**	**Option**	**Type**	**Strategy (reference)**	**Method (reference)**	**Effectiveness**	**Investment**	**Operation and maintenance**
		B7.2.5b	Using SCADA or equivalent systems to continuously check/control pump operation/network pressure	P	Minimize malfunction/failure events by implementing proper inspection and maintenance of pump and gauges functioning and condition. Use of SCADA or equivalent systems to continuously check/control pump operation/network pressures. Assure redundancy.	Best practices programmed monitoring and maintenance of pumps functioning and condition.	While dependant on the conditions of each system, risk reduction effect is high, particularly if pump backups and/or system redundancy are assured.	Required equipment investment costs are site specific. It may be moderate to high if pump backups need to be implemented.	No specific costs are added to those required for routine operation and maintenance of the system.
		B7.2.5c	System redundancy. Availability of backup pumps. Using SCADA or equivalent systems to continuously check/control pump operation/network pressure and start backup pumps	P	Minimize malfunction/failure events by implementing proper inspection and maintenance of pump and gauges functioning and condition. Use of SCADA or equivalent systems to continuously check/control pump operation/network pressures. Assure redundancy.	Best practices programmed monitoring and maintenance of pumps functioning and condition.	While dependant on the conditions of each system, risk reduction effect is high, particularly if pump backups and/or system redundancy are assured.	Required equipment investment costs are site specific. It may be moderate to high if pump backups need to be implemented.	No specific costs are added to those required for routine operation and maintenance of the system.

Hazardous event (ref. from THDB)		Risk reduction option/Barriers			Strategy and some examples on methods from the literature			Costs	
(no.)	**(description)**	**Ref.**	**Option**	**Type**	**Strategy (reference)**	**Method (reference)**	**Effectiveness**	**Investment**	**Operation and maintenance**
7.2.6	Pump stoppage due to power failure/disruption and failing power back-up supply	B7.2.6a	Back-up power facilities automatically switched-on, the moment the utility power supply is interrupted. Protection of pump motor to lightning, loss of voltage or loss of phase. Redundancy of power supply.	P	Prevent that no disruptions occur in the power supply to pumps. Assure resilience against voltage drops or phase loss.	Install back-up power facilities that automatically switch-on whenever electric power supply is interrupted. Installation of a complete redundant electrical connection.	High effect is expected from these risk reduction options.	Investment costs may be low to high, depending on the existing conditions.	No specific costs are added to those required for routine operation and maintenance of the system. Some costs for maintaining a back-up power generator.
7.2.7	Excessively high pressure in the network due to wrong settings or deficient control of pumps operation	B7.2.7a	Installation of pump discharge pressure reducing valves. Using SCADA or equivalent systems to continuously check/control pump operation/network pressure	P	Prevent that pumps do not deliver excessively high pressures.	Install devices to control pump discharge pressure. Reliable monitoring of network pressures.	High effect is expected from these risk reduction options.	Investment costs may be low to high, depending on the existing conditions.	No specific costs are added to those required for routine operation and maintenance of the system.
7.2.8	Low pressure in the network due to wrong settings, deficient metering or deficient control of pumps operation	B7.2.8a	Using SCADA or equivalent systems to continuously check/control pump operation/network pressure	P	Prevent that pumps do not deliver excessively low pressures.	Reliable monitoring of network pressures and pump settings.	High effect is expected from these risk reduction options.	Except if monitoring/controlling systems need to be installed, low investment costs may be expected.	No specific costs are added to those required for routine operation and maintenance of the system.
7.2.9	Contaminant sucked in at the suction side of a pump (where pressure is dynamically reduced)	B7.2.9a	Checking of pump lines design and installation, and monitoring of pump suction pressure	C	Eliminate conditions allowing for suction of materials or fluids by pumps.	Proper design, installation, inspection and functioning of pumps.	High effect is expected from these risk reduction options.	No specific investment costs are required.	No specific costs are added to those required for routine operation and maintenance of the system.
7.2.10	Introduction of pollutants by improper use of material or operational errors	B7.2.10a	Isolation of pumps during installation, maintenance or repair. Enforcement of legislation on materials and compounds in contact with water for human consumption	P	Prevent the use of improper materials in pumps installation, maintenance and repairing.	Use of the products complying with National Acceptance Scheme for products in contact with drinking water.	High effect is expected from these risk reduction options.	Low cost.	

Hazardous event (ref. from THDB)		Risk reduction option/Barriers			Strategy and some examples on methods from the literature			Costs	
(no.)	**(description)**	**Ref.**	**Option**	**Type**	**Strategy (reference)**	**Method (reference)**	**Effectiveness**	**Investment**	**Operation and maintenance**
7.2.11	Poor hygiene during pump installation, maintenance or repair	B7.2.11a	Isolation of pumps during installation, maintenance or repair. Proper cleaning and disinfection before putting new or repaired pumps in service	P	Proper installation, maintenance and repair practices and materials to prevent contamination of water.	Implement operation and maintenance best practices.	Generally best practices prevent risks effectively	Relatively low costs for personnel training and best practices implementation.	No specific costs are added to those required for routine operation and maintenance of the system.
		B7.2.11b	Medical control/licensing of the pump installation, maintenance and repair personnel	P	Prevent waterborne transmissible-disease carriers to come into contact with the distribution system of potable water supplies (Ainsworth and Holt, 2004).	A medical officer should review the suitability of individuals for restricted operations at regular intervals (Ainsworth and Holt, 2004).	Regular personnel-health checks prevent most risks effectively.	No investment costs are required	Relatively low costs for personnel health checks.
7.2.12	Pump operation leading to rapid changes in water flow rate or direction (tidal flows)	B7.2.12a	Continuous monitoring and automatic control of pump delivered pressure/flows by using SCADA or equivalent systems.	C	Minimize malfunction/failure events by implementing proper inspection and maintenance of pump and gauges functioning and condition. Use of SCADA or equivalent systems to continuously check/control pump operation/network pressures. Assure redundancy.	Best practices programmed monitoring and maintenance of pumps functioning and condition (Chambers et al., 2004; Sægrov et al., 2010).	Expectable risk reduction effect is high.	Required equipment investment costs are site specific. It may be moderate to high if pump backups and redundancy need to be implemented.	No specific costs are added to those required for routine operation and maintenance of the system.
7.3 Valves (both in reservoirs as in pumping stations)									

Hazardous event (ref. from THDB)		Risk reduction option/Barriers			Strategy and some examples on methods from the literature			Costs	
(no.)	**(description)**	**Ref.**	**Option**	**Type**	**Strategy (reference)**	**Method (reference)**	**Effectiveness**	**Investment**	**Operation and maintenance**
7.3.1	Inadequate designed or operated valve, malfunctioning valve	B7.3.1a	System redundancy. Periodic valve exercising followed by repair or replacement as needed. Use of SCADA output data on control valve operational status	C	Provide that valves have adequate characteristics and functioning.	Best practices programmed inspection and maintenance of valves functioning and condition (Chambers et al., 2004; Sægrov et al., 2010).	Expected risk reduction effect is high.	Moderate to high costs for SCADA and monitoring devices if these systems need to be installed.	No specific costs are added to those required for routine inspection and maintenance of the system.
		B7.3.1b	Use of SCADA or equivalent systems to control valves accordingly to network required pressures/flows	C	Have valves operated automatically, accordingly to network appropriate pressures.	Use of SCADA or equivalent systems	Expected risk reduction effect is high.	Moderate to high costs for SCADA and monitoring devices installation.	Relatively low costs for SCADA operation and maintenance.
7.3.2	Damage or destruction of network pipes due to water hammers	B7.3.2a	Install surge control devices (e.g., air vessels, surge anticipation valves) close to major valves and at vulnerable locations in the system, which can be identified through a comprehensive surge analysis of the network	C/P	Prevent the development of destructive surge pressures by proper design, equipment and operation of the system (Chambers et al., 2004).	Make a surge analysis of the distribution system to find critical sectors and, accordingly, install anti surge equipment. Implement good practices for pump and valve manoeuvring (Chambers et al., 2004).	Although dependent on the conditions of each system, destructive surge pressures are generally prevented with efficiently.	Even if generally of moderately cost, required equipment investment depends on the existing conditions. Operational good practices implementation and personnel training have relatively low costs.	No specific costs are added to those required for routine operation and maintenance of the system.
7.3.3	Introduction of pollutants by improper use of material or operational errors	B7.3.3a	Enforcement of legislation on materials and compounds in contact with water for human consumption	C/P	Prevent the use of improper materials in pumps installation, maintenance and repairing.	Use of the products complying with National Acceptance Scheme for products in contact with drinking water.	High effect is expected from these risk reduction options.	Low cost.	

Hazardous event (ref. from THDB)		Risk reduction option/Barriers			Strategy and some examples on methods from the literature			Costs	
(no.)	**(description)**	**Ref.**	**Option**	**Type**	**Strategy (reference)**	**Method (reference)**	**Effectiveness**	**Investment**	**Operation and maintenance**
		B7.3.3b	Proper cleaning and disinfection before putting new or repaired valves in service	P	Correct installation, maintenance and repair practices and materials to prevent contamination of water.	Implement operation and maintenance best practices (Chambers et al., 2004; Sægrov et al., 2010).	Generally best practices prevent risks effectively	Relatively low costs for personnel training and best practices implementation.	No specific costs are added to those required for routine operation and maintenance of the system.
7.3.4	Poor hygiene during installation, maintenance or repair of valves	B7.3.4a	Proper cleaning and disinfection before putting new or repaired valves in service	P	Correct installation, maintenance and repair practices and materials to prevent contamination of water.	Implement operation and maintenance best practices (Chambers et al., 2004; Sægrov et al., 2010).	Generally best practices prevent risks effectively	Relatively low costs for personnel training and best practices implementation.	No specific costs are added to those required for routine operation and maintenance of the system.
		B7.3.4b	Medical control/licensing of the valves installation, maintenance and repair personnel	P	Prevent waterborne transmissible-disease carriers to come into contact with the distribution system of potable water supplies (Ainsworth and David Holt, 2004).	A medical officer should review the suitability of individuals for restricted operations at regular intervals (Ainsworth and David Holt, 2004).	Regular personnel-health checks prevent most risks effectively.	No investment costs are required	Relatively low costs for personnel health checks.
7.3.5	Inadequate settings or control, or malfunctioning/failure of pressure reducing valve	B7.3.5a	System redundancy. Periodic valve exercising followed by repair or replacement as needed. Use of SCADA output data on control valve operational status	P	Minimize malfunction/failure events by implementing proper inspection and maintenance of valves and gauges functioning and condition. Use of SCADA or equivalent systems to continuously check/control pump operation/network pressures. Assure redundancy.	Best practices programmed monitoring and maintenance of pumps functioning and condition (Chambers et al., 2004; Sægrov et al., 2010).	Expectable risk reduction effect is high.	Required equipment investment costs are site specific. It may be moderate to high if pump backups and redundancy need to be implemented.	No specific costs are added to those required for routine operation and maintenance of the system.

8. Technical efficiency of existing risk reduction options in transport and distribution (from trunk main to the water meter)

The risk reduction options/barriers correspond to the items in the TRRDB, subsystem 8.

Hazardous event (ref. from THDB)		Risk reduction option/Barriers			Strategy and some examples on methods from the literature			Costs (reference)	
(no.)	(description)	Ref.	Option	Type	Strategy (reference)	Method (reference)	Effectiveness (reference)	Investment	Operation and maintenance
8.1 Network									
8.1.1	Pipe burst due to extreme external-stresses (e.g. storms, earthquakes, landslides, freezing and thawing, traffic incidents, etc.)	B8.1.1a	Systems redundancy, operational flexibility and alternative or backup supply.	P/C	Assure continuity of water supply by the distribution system or, alternatively, by other resources.	Have system redundancy or alternative backup supply (Chambers et al., 2004; Sægrov et al., 2010).	Effect of risk reduction is pipe, system and utility specific.	Moderate to high depending on existing conditions.	No specific costs are added to those required for routine operation and maintenance of the system.
		B8.1.1b	Plan and practice of emergency response	C	Assure to be prepared of pipe bursts and their consequences. Making plans and practice them.	Make an analysis at what locations considerable effects are to be expected. Make emergency planning, including communication measures.	Being well-prepared can have a significant impact on the consequences of a pipe burst, however pipe, system and utility specific.	Low cost.	Low costs, moderate for mains with high consequences by bursts.
8.1.2	Pipe burst due to increased external-stresses on pipe (e.g. traffic, soil movement, etc) in combination with a reduced pipe condition	B8.1.2a	Systems redundancy, operational flexibility and/or supply-backups	P/C	Assure continuity of water supply by the distribution system or, alternatively, by other resources.	Have system redundancy or alternative backup supply (Chambers et al., 2004; Sægrov et al., 2010).	Risk reduction effect is pipe, system and utility specific.	Moderate to high depending on existing conditions.	No specific costs are added to those required for routine operation and maintenance of the system.
		B8.1.2b	See B8.1.1.b	C	See B8.1.1.b	See B8.1.1.b	See B8.1.1.b	See B8.1.1.b	See B8.1.1.b
8.1.3	Pipe burst due to bad condition of pipe (e.g. internal /external corrosion)	B8.1.3a	Systems redundancy, operational flexibility and/or supply-backups	P	Minimize burst frequency. Assure continuity of water supply by the distribution system or, alternatively, by other resources.	Using pipes made of materials and characteristics suited for the existing soil, and implementing a sound rehabilitation program. Have system redundancy or alternative backup supply (Chambers et al., 2004; Sægrov et al., 2010).	Risk reduction effect is pipe, system and utility specific.	Moderate to high, depending on existing conditions.	No specific costs are added to those required for routine operation and maintenance of the system.
		B8.1.3b	See B8.1.1.b	C	See B8.1.1.b	See B8.1.1.b	See B8.1.1.b	See B8.1.1.b	See B8.1.1.b

Hazardous event (ref. from THDB)		Risk reduction option/Barriers			Strategy and some examples on methods from the literature			Costs (reference)	
(no.)	(description)	Ref.	Option	Type	Strategy (reference)	Method (reference)	Effectiveness (reference)	Investment	Operation and maintenance
8.1.4	Pipe burst due to increased internal-stress (e.g. pressure, transients)	B8.1.4.a	Systems redundancy, operational flexibility and/or supply-backups. Continuous monitoring and automatic control of the pressure throughout the entire network by using SCADA or equivalent systems.	C	Minimize burst frequency. Assure continuity of water supply by the distribution system or, alternatively, by other resources.	Make a pressure and surge analysis of the distribution system to find critical sectors and, accordingly, install anti surge equipment. Implement good practices for pump and valve manoeuvring (Chambers et al., 2004).	Risk reduction effect is pipe and system specific.	Moderate to high depending on existing conditions.	No specific costs are added to those required for routine operation and maintenance of the system.
		B8.1.4.b	See B8.1.1.b	C	See B8.1.1.b	See B8.1.1.b	See B8.1.1.b	See B8.1.1.b	See B8.1.1.b
8.1.5	Loss of pipes' hydraulic capacity due to scaling/tubercle formation	B8.1.5	Rehabilitation of the affected network zones	C	Eliminate significant pressure-losses in network pipes.	Implementation of a sound rehabilitation program (Vitanage et al., 2004; Sægrov et al., 2010).	Risk reduction effect is pipe and system specific.	Moderate to very high depending on existing conditions.	No specific costs are added to those required for routine operation and maintenance of the system.
8.1.6	Insufficient network capacity due to inadequate design				Eliminate or minimize network hydraulic deficiencies.	Correct network design or change operation to mitigate existing hydraulic limitations (Vitanage et al., 2004; Sægrov et al., 2010).	Risk reduction effect is system specific.	Moderate to very high depending on existing conditions.	No specific costs are added to those required for routine operation and maintenance of the system.
8.1.7	Poor hygiene during pipes installation/repair	B8.1.7a	Checking of the microbiological quality of the installed/repaired zone water before putting pipes in service	P	Prevent contaminated water to ingress into the network.	Implement operation and maintenance best practices (Sægrov et al., 2010).	Generally best practices prevent risks effectively	Relatively low costs for personnel training and best practices implementation.	No specific costs are added to those required for routine operation and maintenance of the system.
		B8.1.7b	Medical control/licensing of the installation/repair personnel	P	Prevent waterborne transmissible-disease carriers to come into contact with the distribution system of potable water supplies (Ainsworth and David Holt, 2004).	A medical officer should review the suitability of individuals for restricted operations at regular intervals (Ainsworth and David Holt, 2004).	Regular personnel-health checks prevent most risks effectively	No investment costs are required	Relatively low costs for personnel health checks.

Hazardous event (ref. from THDB)		**Risk reduction option/Barriers**			**Strategy and some examples on methods from the literature**			**Costs (reference)**	
(no.)	(description)	Ref.	Option	Type	Strategy (reference)	Method (reference)	Effectiveness (reference)	Investment	Operation and maintenance
8.1.8	Intrusion of contaminated water due to low (negative) pressure in the network, in combination with cracks or leaking joints	B8.1.8a	Continuous monitoring and automatic control of the pressure throughout the entire network by using SCADA or equivalent systems. Wherever necessary, use pressure boosting pumps.	P	Mitigate the possibility of contaminated water to ingress into the network though pipe fissures or cracks.	Prevent the occurrence of low / negative pressure in the network. Provide that pipes are in good condition by implementing a sound rehabilitation program. Ensure that the capacity of the network is sufficient to prevent low pressures (Vitanage et al., 2004; Sægrov et al., 2010).	Risk reduction effect highly dependent of the network conditions and operation.	Moderate to high depending on network pipe conditions.	No specific costs are added to those required for routine operation and maintenance of the system.
		B8.1.8b	Have air vessels installed close to pumps and major valves, control the rate of pumps switching and operate valves and hydrants slowly	C	Prevent the occurrence low or negative pressures in the network.	Make a surge analysis of the distribution system to find critical sectors and, accordingly, install anti surge equipment. Implement good practices for pump and valve manoeuvring (Chambers et al., 2004; Sægrov et al., 2010).	Although dependent on the conditions of each system, low / negative pressures are generally prevented effectively	Even if generally of moderately cost, required equipment investment depends on the existing conditions. Operational good practices implementation and personnel training have relatively low costs.	No specific costs are added to those required for routine operation and maintenance of the system.
8.1.9	Vinyl chloride leaching from unplasticized or old (manufactured prior to 1977) PVC pipes	B8.1.9a	Monitoring of vinyl chloride in the delivered water. Enforcement of legislation on materials in contact with water for human consumption	C	Do not use or replace pipes of material that may release contaminants.	Use of the products complying with National Acceptance Scheme for products in contact with drinking water.	High effect is expected from these risk reduction options.	Moderate to very high depending on existing conditions.	

Hazardous event (ref. from THDB)		Risk reduction option/Barriers			Strategy and some examples on methods from the literature			Costs (reference)	
(no.)	(description)	Ref.	Option	Type	Strategy (reference)	Method (reference)	Effectiveness (reference)	Investment	Operation and maintenance
8.1.10	Leaching of contaminants from cement made or lined pipes	B8.1.10a	Monitoring of aluminium, arsenic, barium, chromium and cadmium in water. Ensuring that water is non-aggressive	P	Detect and prevent or mitigate contaminant release from pipes.	Proper monitoring of network water chemical quality. Replace pipes and/or lower the water aggressiveness (Vitanage et al., 2004; Sægrov et al., 2010).	High (pipe replacement) to moderate effect is expected from these risk reduction options.	High costs may be required for pipe rehabilitation or water aggressiveness removal at treatment.	In detecting contaminants, no specific costs are added to those required for routine monitoring of the network water quality.
8.1.11	Leaching of organic compounds from bituminous sealants and linings	B8.1.11a	Monitoring of PAHs, taste and odour, in the delivered water. Enforcement of legislation on materials in contact with water for human consumption	P	Do not use repairing materials that may release contaminants.	Use of the products complying with National Acceptance Scheme for products in contact with drinking water.	High effect is expected from these risk reduction options.	Low cost.	
8.1.12	Permeation of organic-pollutants in the soil through rubber joints or the (PE or PVC) pipe wall	B8.1.12a	Monitoring of water for organic contaminants (e.g., PAHs, VOCs), taste and odour	P	Detect and prevent or mitigate organic contaminant ingress.	Proper monitoring of network water chemical quality. Replace permeable pipes wherever necessary (USEPA, 2002).	An effect detection of organic contaminants is expectable. Significant risk reduction may be achieved by pipe or joint replacement.	Moderate to high depending on existing conditions.	In detecting contaminants, no specific costs are added to those required for routine monitoring of the network water quality.
8.1.13	Backflow or back-siphonage of non-potable water (e.g., wastewater) or fluids (e.g., industrial)	B8.1.13a	Installation of backflow protection devices at all points of the network where the possibility exists for water from any other source to enter the public water supply system (e.g., points of delivery, fire lines, hydrants, etc.). The type and condition of the devices must be appropriate for the corresponding hazard level	P	Prevent ingress of contaminated water from non-potable sources (e.g., urban / industrial wastewater).	Eliminating cross-connections or protecting the water supply system using backflow prevention devices and assemblies, using the Montout classification (USEPA, 2003).	High risk-reduction effect is expectable.	Investment costs are generally low to moderate.	In detecting contaminants, no specific costs are added to those required for routine monitoring of the network water quality.

Hazardous event (ref. from THDB)		Risk reduction option/Barriers			Strategy and some examples on methods from the literature			Costs (reference)	
(no.)	(description)	Ref.	Option	Type	Strategy (reference)	Method (reference)	Effectiveness (reference)	Investment	Operation and maintenance
8.1.14	Too long residence times of water in the network	B8.1.14a	Keep effective concentrations of disinfectant residual. Rigorous monitoring of the microbiological quality of the water	P	Prevent and monitor possible excessive-microbial regrowth.	Operationally minimize transit times throughout the whole network, keep effective disinfectant residual concentrations and properly monitor the microbiological quality of the network water. Another option is to minimize AOC or BDOC in the treated water . (Chambers et al., 2004; Sægrov et al., 2010).	Risk reduction effect depends on network specific conditions.	Investment costs may be low to high depending on network conditions or the required additional treatment.	No specific costs are added to those required for routine monitoring of the network water quality.
		B8.1.14b	See B8.1.14.a	P	See B8.1.14.a	See B8.1.14.a	See B8.1.14.a	See B8.1.14.a	See B8.1.14.a
		B8.1.14c	See B8.1.14.a	P	See B8.1.14.a	See B8.1.14.a	See B8.1.14.a	See B8.1.14.a	See B8.1.14.a
8.1.15	Deficit in disinfectant residual, excess in water AOC/BDOC	B8.1.15a	Continuous monitoring and automatic control of disinfectant residual in the entire network by using SCADA or equivalent systems.	P	Prevent and monitor possible excessive-microbial regrowth.	Control water disinfectant residual and AOC/BDOC concentrations (Chambers et al., 2004; Payment and Robertson2004).	Risk reduction effect is generally satisfactory.	Moderate to high investment costs may be necessary if new equipment is needed for boosting disinfectant concentrations or minimize/remove AOC treatment outputs.	No specific costs are added to those required for routine monitoring of the network water quality.
		B8.1.15b	Monitoring and control of treated water AOC and of microbiological quality throughout the distribution system	P	Prevent and monitor possible excessive-microbial regrowth.	Control water disinfectant residual and AOC/BDOC concentrations (Chambers et al., 2004; Payment and Robertson, 2004).	Risk reduction effect is generally satisfactory.	Moderate to high investment costs may be necessary if new equipment is needed for boosting disinfectant concentrations or minimize/remove AOC treatment outputs.	No specific costs are added to those required for routine monitoring of the network water quality.
8.1.16	Too high dosage of disinfectant residual (e.g., malfunctioning dosing pump's))	B8.1.16a	Continuous monitoring and automatic control of disinfectant residual in the entire network by using SCADA or equivalent systems.	C/P	Prevent the occurrence of excessive concentrations of disinfectant residual.	Effective control and monitoring of the disinfectant residual concentrations within limits prescribed by WHO (WHO, 2006).	Risk reduction effect is generally satisfactory.	Moderate to high investment costs may be necessary if new equipment is needed for controlling / boosting disinfectant concentrations.	No specific costs are added to those required for routine monitoring of the network water quality.

Hazardous event (ref. from THDB)		Risk reduction option/Barriers			Strategy and some examples on methods from the literature			Costs (reference)	
(no.)	(description)	Ref.	Option	Type	Strategy (reference)	Method (reference)	Effectiveness (reference)	Investment	Operation and maintenance
8.1.17	Re-suspension of sediments or sloughing of tubercle/biofilm due to rapid changes in water flow rate or direction	B8.1.17a	Continuous monitoring and automatic control of pressure throughout the network by using SCADA or equivalent systems. Continuous monitoring of network water turbidity	C/P	Avoid rapid raises in water flow rate	Control network pressure/flow rates preventing abrupt changes in water velocity (Chambers et al., 2004).	Risk reduction effect depends on network specific conditions.	Investment costs may be not necessary. Moderate to high investment costs may be necessary if new equipment (e.g., SCADA) is needed for monitoring / controlling flow rates.	No specific costs are added to those required for routine control of the network flow rates.
		B8.1.17b	Regularly flushing of dead-end and low flow pipes, and of those within areas receiving water rich in sediments	P	Remove sediments from the network to minimize their accumulation.	Clean critical sectors of the network (e.g., dead-end and low flow pipes) by applying unidirectional flushing (Vreeburg et al., 2009; Sægrov et al., 2010).	Risk reduction effect depends on network specific conditions.	No significant investment costs required.	Programmed flushing to maintain low sediment levels in the network may have moderate to high costs (although low compared to redesign).
8.1.18	Intentional contamination of the network water (terrorism, sabotage, vandalism, arson)	B8.1.18a	Enhanced security by monitoring/controlling and eliminating unauthorized access to critical facilities and ensuring physical protection. Plan and practice emergency response procedures.	P	Identify critical points allowing for intentional addition of contaminants to the systems water. Prevent access to the critical points. Establish conditions for fast implementation of measures to protect the consumers' health.	Whole system vulnerability-assessment of critical points allowing for intentional addition of contaminants. Access to critical points efficiently controlled by physical barriers and monitoring (AWWA, 2001).	Incident probability highly reduced (AWWA, 2001).	Access monitoring equipment (e.g., video cameras) of relatively low cost.	Staff and maintenance of vigilance network, and emergency plan implementation costs are relatively low .

Hazardous event (ref. from THDB)		Risk reduction option/Barriers			Strategy and some examples on methods from the literature			Costs (reference)	
(no.)	(description)	Ref.	Option	Type	Strategy (reference)	Method (reference)	Effectiveness (reference)	Investment	Operation and maintenance
		B8.1.18b	On-line measurements based early-warning systems. Viewing consumer complaints (e.g., discoloration, unusual taste or odour) or increase in illnesses at emergency medical care facilities as warnings	C	Timely detection of water contamination. Establish conditions for prompt implementation of measures to protect the consumers' health.	Watch for sudden and significant changes in water quality routine-monitoring parameters (e.g., chlorine, conductivity, turbidity, pH) that may be indicative of water contamination. Survey consumer complaints and public health information as potential warnings. Enforcement of Emergency Response Plan (ERP) (AWWA, 2001).	Effect of changes in routine-monitoring parameters behaviour limited to some types and concentrations of contaminants. Warnings from complaints and public health inputs restricted to persistent contamination. Effect of emergency response is highly dependent of the specificity of the problem and conditions.	Emergency response plan implementation has moderate costs. No other investment costs are specifically required.	Relatively low staff-costs in surveying monitoring, complaints and public health inputs, and emergency response plan training, maintenance and updating.
		B8.1.18c	Real-time early-warning systems based on fingerprint pattern changes	C	Real-time detection of water contamination. Establish conditions for prompt implementation of measures to protect the consumers' health.	Online monitoring / survey of sudden and significant changes in water spectroscopic fingerprints as contamination alerts. Enforcement of Emergency Response Plan (AWWA, 2001; van den Broeke, 2007).	Effect of changes in fingerprints limited to some types and concentrations of contaminants. Effect of emergency response is highly dependent of the specificity of the problem and conditions.	Costs for probes acquisition and installation may be low to high, depending on the network dimension and complexity. Emergency response plan implementation has moderate costs.	Relatively low costs are required for probes operation, maintenance and data survey, as well as for emergency response plan training, maintenance and updating.
		B8.1.18d	Early-warning systems based on toxicity monitoring systems/programme	C	Prompt detection of toxicants in water. Establish conditions for timely implementation of measures to protect the consumers' health.	Online monitoring the water toxicity. Enforcement of Emergency Response Plan (AWWA, 2001; Moldaenke et al., 2008).	Efficiency of detecting water toxicity limited to some types and concentrations of contaminants. Efficiency of emergency response is highly dependent of the specificity of the problem and conditions.	Costs for acquisition and installation of toxicity detecting systems may be moderate to high depending on the type of the system and on the network dimension and complexity. Emergency response plan implementation has moderate costs.	Relatively low costs are required for toxicity detecting systems operation, maintenance and data survey, as well as for emergency response plan training, maintenance and updating.

Hazardous event (ref. from THDB)		Risk reduction option/Barriers			Strategy and some examples on methods from the literature			Costs (reference)	
(no.)	(description)	Ref.	Option	Type	Strategy (reference)	Method (reference)	Effectiveness (reference)	Investment	Operation and maintenance
8.1.19	Malfunctioning or failure of valves and/or (boosting) pumps	B8.1.19a	System redundancy. Availability of backup pumps and power generators.	C/P	Assure continuity of water supply by the distribution system or, alternatively, by other resources. Minimize pump malfunction / failure frequency.	Have system redundancy or alternative backup pumps and supply. Implement operation and maintenance best practices (Vitanage et al., 2004; Sægrov et al., 2010).	Generally best practices prevent risks effectively	Relatively low costs for personnel training and best practices implementation.	No specific costs are added to those required for routine operation and maintenance of the system.
		B8.1.19b	System's protection against cyber attack threats (e.g. hackers and malware such as worms and viruses) and establish fast-response capabilities	P	Minimize vulnerability of computer-based monitoring and control system (e.g., SCADA) against cyber attack threats and implement prompt response capabilities.	Perform regular vulnerability assessments of computer based systems and assure robustness of their protection against hackers and malware (e.g., worms, viruses). Training and updating personnel proficiency on good practice for computer based process control. Implement prompt response capabilities (AWWA; 2001).	Risk reduction effect highly dependent on of the achieved degree of protection robustness.	Costs for protection software and best practices implementation are relatively low.	Costs for updating / maintenance of protection software and best practices are relatively low.
8.1.20	Valve pit flood allowing contaminants intrusion through defective valve sealing, in combination with low pressure in the network	B8.1.20a	Air valves equipped with inflow preventer devices. Permeation proof valve-sealings.	P	Mitigate conditions for valve pits flooding. Prevent contaminant ingress through valve sealings.	Proper pit valve pits design, location or rehabilitation. Use of inflow preventer devices and permeation proof valve sealings. Implement operation and maintenance best practices (Vitanage et al., 2004; Sægrov et al., 2010).	Effective risk reduction is expectable from these risk reduction measures.	Low investment costs may be required.	No specific costs are added to those required for routine operation and maintenance of the system.

Hazardous event (ref. from THDB)		Risk reduction option/Barriers			Strategy and some examples on methods from the literature			Costs (reference)	
(no.)	(description)	Ref.	Option	Type	Strategy (reference)	Method (reference)	Effectiveness (reference)	Investment	Operation and maintenance
		B8.1.20b	Proper maintenance and repair of valves	P	Mitigate conditions for valve pits flooding. Prevent contaminant ingress through valve sealings.	Proper pit valve pits design, location or rehabilitation. Use of inflow preventer devices and permeation proof valve sealings. Implement operation and maintenance best practices (Vitanage et al., 2004; Sægrov et al., 2010).	Effective risk reduction is expectable from these risk reduction measures.	Low investment costs are required.	No specific costs are added to those required for routine operation and maintenance of the system.
8.1.21	Inadequate settings or control, or malfunctioning/failur e of pressure reducing valve	B8.1.21a	Proper setting, maintenance and repair of pressure reducing valves	P	Prevent excessive pressure in network water due inadequate settings or control, or malfunctioning/failur e of pressure reducing valves.	Implement operation and maintenance best practices (Chambers et al., 2004; Sægrov et al., 2010).	Effective risk reduction is expectable from these risk reduction measures.	Low investment costs are required.	No specific costs are added to those required for routine operation and maintenance of the system.
8.1.22	Defective or clogged fire hydrant	B8.1.22a	Proper inspection, maintenance and repair of hydrants	P	Prevent deficiencies in hydrants' functioning.	Implement operation and maintenance best practices (Chambers et al., 2004; Sægrov et al., 2010).	Generally best practices prevent risks effectively	No investment costs are required	No specific costs are added to those required for routine operation and maintenance of the system.
8.1.23	Inflow of sediments and corrosion materials accumulated in hydrants	B8.1.23a	Hydrants equipped with backflow protection devices	C	Prevent network-water contamination by ingress of hydrant sediments and corrosion materials.	Provide that hydrants have backflow protection devices. Implement operation and maintenance best practices (USEPA, 2003).	Effective risk reduction is expectable from these risk reduction measures.	No significant investment costs are required	No specific costs are added to those required for routine operation and maintenance of the system.
8.2 Water meters and non-return prevention devices									
8.2.1	Wear of water meter mechanical-parts	B8.2.1a	Abnormal or uneven consumption trends monitoring	P	Prevent wrong consumption measurements due to meters malfunctioning.	Survey for deviations from consumption trends that may indicate poor conditions of meters.	Statistically significant risk reduction is expectable from these risk reduction measures.	No significant investment costs are required	No specific costs are added to those required for routine operation and maintenance of the system.

Hazardous event (ref. from THDB)		Risk reduction option/Barriers			Strategy and some examples on methods from the literature			Costs (reference)	
(no.)	(description)	Ref.	Option	Type	Strategy (reference)	Method (reference)	Effectiveness (reference)	Investment	Operation and maintenance
8.2.2	Freezing of water within meters and/or external pipes exposed to extremely low temperatures	B8.2.2	Insulate meters, valves and connected pipes	P	Prevent disruption of supply due to freezing of the water within meters or external pipes.	Protect meters, valves and external pipes against freezing .	Statistically significant risk reduction is expectable from these risk reduction measures.	No significant investment costs are required	No specific costs are added to those required for routine operation and maintenance of the system.
8.2.3	Fouling of water meter due to sediments or biofilm	B8.2.3a	Implement best practice protocols for water meter inspection and maintenance. Point-of-entry water filtration	P/C	Prevent disruption of supply due to water meter fouling.	Minimize sediment transport from the network. Implement operation and maintenance best practices (Vreeburg et al., 2009; Sægrov et al., 2010).	Effect of risk reduction is network specific.	No significant investment costs are required	Reduction of sediment loads may require moderate to high costs. Otherwise, no other costs are added to those required for routine operation and maintenance of the system.
8.2.4	Fouling of non-return prevention devices due to build-up of sediments or biofilm	B8.2.4a	Implement best practice protocols for non-return prevention devices inspection and maintenance.	P	Prevent disruption of supply due to fouling of non-return prevention devices.	Minimize sediment transport from the network. Implement operation and maintenance best practices (Vreeburg et al., 2009; Sægrov et al., 2010).	Effect of risk reduction is network specific.	No significant investment costs are required	Reduction of sediment loads may require moderate to high costs. Otherwise, no other costs are added to those required for routine operation and maintenance of the system.
8.2.5	Absent, inadequate or defective non-return prevention devices allow backflow or siphonage of contaminated water from costumer premises or fire hydrants	B8.2.5a	Enforcement of legislation on mandatory backflow preventing devices use and inspection	P	Prevent backflow or siphonage of contaminated water from costumer premises or fire hydrants.	Assure proper installation and functioning of backflow preventing devices at points of entry and fire hydrants. Implement operation and maintenance best practices, using Montout classification (USEPA, 2003; Sægrov et al., 2010).	Effective risk reduction is expected from the risk reduction options.	No significant investment costs are required	No specific costs are added to those required for routine operation and maintenance of the system.

Hazardous event (ref. from THDB)		Risk reduction option/Barriers			Strategy and some examples on methods from the literature			Costs (reference)	
(no.)	(description)	Ref.	Option	Type	Strategy (reference)	Method (reference)	Effectiveness (reference)	Investment	Operation and maintenance
8.2.6	Meter pit flood allowing contaminants intrusion thought defective sealing, in combination with low pressure in the network	B8.2.6a	Permeation proof meter and valve-sealings.	C	Mitigate conditions for meter pits flooding. Prevent contaminant ingress through meter sealings. Control network pressure.	Proper pit valve pits design, location or rehabilitation. Use of inflow preventer devices and permeation proof meter sealings. Implement operation and maintenance best practices. Control network pressure (Chambers et al., 2004; Sægrov et al., 2010).	Effective risk reduction is expectable from these risk reduction measures.	Low investment costs may be required.	No specific costs are added to those required for routine operation and maintenance of the system.

9. Technical efficiency of existing risk reduction options in internal piping

The risk reduction options/barriers correspond to the items in the TRRDB, subsystem 9.

Hazardous event (ref. from THDB)		Risk reduction option/Barriers			Strategy and some examples on methods from the literature			Costs (reference)	
(no.)	**(description)**	**Ref.**	**Option**	**Type**	**Strategy (reference)**	**Method (reference)**	**Effectiveness (reference)**	**Investment**	**Operation and maintenance**
9.1 Drinking water installation									
9.1.1	Bad design of the installation or low pressure in distribution network	B9.1.1a	Adjustment of the network design or operation to prevent low pressure (e.g., use alternative or new mains)	P	Provide that network pressure is enough to deliver water with adequate pressure to all building floors	Adjust network operation or design (e.g., use alternative or new mains) to deliver adequate pressure (Chambers et al., 2004; Sægrov; 2010).	Risk reduction is effective.	Investment costs from null to very high depending on the existing network conditions (e.g., need for new mains).	No specific costs are added to those required for routine operation of the distribution network.
		B9.1.1b	Design and installation of new reservoirs or boost pump stations by accredited professionals	C	Assure proper design of network reservoirs or boost pump stations (Sægrov; 2010).	Require that network design is made by proficiency certified professionals.	Risk reduction is effective.	No investment costs are required.	No specific costs are required for operation and maintenance.
9.1.2	Failure of booster pump in multi-storey buildings	B9.1.2a	Proper repair of booster pump. Availability of a back-up pump	C	Mitigate frequency of malfunctioning or failure of multi-storey buildings' booster-pumps.	Proper maintenance and repair of multi-storey buildings' booster-pumps. Availability of back-up pumps (Vitanage, 2004; Sægrov; 2010).	Risk reduction is effective.	Relatively low to moderate investment costs, depending on the existing conditions.	No specific costs are added to those required for routine maintenance of the pumps.
9.1.3	Pipe burst due to poor pipe material, excessive pressure, water hammer, building activities (e.g. drilling)	B9.1.2b	Building and plumbing systems design, construction/installation and repair by accredited professionals.	P	Assure that building and plumbing systems design, construction/installation and repair are done by proficient professionals.	Require that building and plumbing systems design, construction/installation and repair are done by accredited professionals (WHO, 2006).	While generally effective, risk reduction may depend on the existing conditions (e.g., plumbing system materials and age).	Relatively low to moderate investment costs, depending on the existing conditions.	No specific costs are added to those required for routine maintenance of the plumbing system.
9.1.4	Excessive pressure in the distribution system	B9.1.4a	Install individual pressure reducing valve	C	Prevent excessive network pressures to be transported to internal pipes system.	Use of pressure reducing valves at the point-of-entry.	Risk reduction is effective.	Low investment costs.	No specific costs are added to those required for routine maintenance of the plumbing system.

Hazardous event (ref. from THDB)		Risk reduction option/Barriers			Strategy and some examples on methods from the literature			Costs (reference)	
(no.)	(description)	Ref.	Option	Type	Strategy (reference)	Method (reference)	Effectiveness (reference)	Investment	Operation and maintenance
9.1.5	Poor hygiene in plumbing systems installation/repair	B9.1.5a	Plumbing systems installation and repair by accredited professionals	P	Assure that plumbing systems installation and repair are done by proficient professionals.	Enforce a national plumbing code of practice, as prescribed by WHO (WHO, 2006) .	Risk reduction is effective.	No investment costs are required.	No operation and maintenance costs are required.
		B9.1.5b	Medical control/licensing of plumbers	P	Prevent waterborne transmissible-disease carriers to come into contact with the plumbing system.	Enforce a national plumbing code of practice, as prescribed by WHO (WHO, 2006) .	Risk reduction is effective.	No investment costs are required.	No operation and maintenance costs are required.
		B9.1.5c	Checking of the microbiological quality of the plumbing system water before putting it in service	P/C	Prevent contamination from new or repaired pipes to enter the system.	Analyze the microbial quality of water delivered by new or repaired pipes (WHO, 2006) .	Risk reduction is effective.	No investment costs are required.	No specific costs are added to those required for routine maintenance of the plumbing system.
9.1.6	Backflow or back-siphonage of contaminated water from other systems (e.g., wastewater, fire protection, garden watering and irrigation)	B9.1.6a	Plumbing done by accredited professionals. Use of backflow prevention devices in connections to other systems (e.g., sprinkler systems or high-pressure mains and hydrants)	P/C	Prevent contaminated water to enter the internal piping system by back-flow / siphonage.	Use of backflow prevention devices. Internal piping system designed and installed by accredited professionals (USEPA, 2003).	Risk reduction is effective.	No significant investment costs are required.	No specific costs are added to those required for routine maintenance of the plumbing system.
9.1.7	Microbial regrowth enhancement by relatively high water-temperature, in cold water pipes, or heating of water by warm objects at close distance	B9.1.7a	Relocate or insulate cold water pipes	P	Prevent heat transfer from hot water pipes or heating devices to cold water pipes.	Insulate or relocate heat sources (WHO, 2006).	Risk reduction is effective.	Relatively low investment costs are required, unless extensive pipe relocation is required.	No specific costs are added to those required for routine maintenance of the plumbing system.
9.1.8	Loss of pipes' hydraulic capacity due to incrustation build-up	B9.1.8a	Enforcement of legislation on network water hardness and silicates content. Remove hardness/silicates with local point-of-entry treatment devices	P/C	Minimize development of hydraulic resistance in pipes due to incrustation build-up.	When appropriate remove water hardness at the treatment plant or at the point-of-entry (USEPA, 2006).	Risk reduction is dependent of the existing conditions.	Low to high costs, depending on the existing conditions.	Cost for operation and/or maintenance of hardness removal are dependent of the source / treated water characteristics.

Hazardous event (ref. from THDB)		Risk reduction option/Barriers			Strategy and some examples on methods from the literature			Costs (reference)	
(no.)	**(description)**	**Ref.**	**Option**	**Type**	**Strategy (reference)**	**Method (reference)**	**Effectiveness (reference)**	**Investment**	**Operation and maintenance**
		B9.1.8b	Prevent corrosion of iron/steel pipes by applying epoxy or polyurethane lining	P	Minimize development of hydraulic resistance in pipes due to incrustation build-up.	Lining of iron pipes to prevent incrustation development.	Risk reduction is effective.	Moderate to high costs, depending on the existing conditions.	No specific costs are added to those required for routine maintenance of the plumbing system.
9.1.9	Corrosion of plumbing system materials, which is promoted by low pH, temperature, insufficient or excessive alkalinity in the water	B9.1.9a	Enforcement of legislation on materials in contact with water for human consumption	P/C	Minimize corrosion of internal pipes.	Use pipes' material adequate to water aggressiveness (WHO, 2006).	Risk reduction is effective.	Low to moderate costs, depending on the existing conditions.	No specific costs are added to those required for routine maintenance of the plumbing system.
		B9.1.9b	Proper pH and alkalinity correction at drinking water treatment plant	P	Minimize corrosion of internal pipes.	When appropriate treat water for aggressiveness at the treatment plant or at the point-of-entry (USEPA, 2006).	Risk reduction is effective.	Low to moderate costs, depending on the existing conditions.	No specific costs are added to those required for routine maintenance of the plumbing system.
9.1.10	Migrating substances from polymer material (e.g. vinyl chloride leaching from PVC pipes)	B9.1.10a	Enforcement of legislation on materials in contact with water for human consumption	P	Do not use or replace pipes of material that may release contaminants.	Use of the products complying with National Acceptance Scheme for products in contact with drinking water.	High effect is expected from these risk reduction options.	Moderate to high depending on existing conditions.	No specific costs are added to those required for routine maintenance of the plumbing system.
9.1.11	Plumbosolvency of lead pipes, which may be promoted by water low-pH and low alkalinity	B9.1.11a	Enforcement of legislation on materials in contact with water for human consumption. Increase the pH to 8.0–8.5 after chlorination and dose orthophosphate	C/P	Eliminate or mitigate plumbosolvency.	Replace lead pipes or solders or minimize plumbosolvency by pH increases an orthophosphate dosing (Hayes et al., 2010).	Lead pipe or solder replacement are effective. Water pH and/or orthophosphate treatment are expected to have moderate effect.	Moderate to high depending on existing conditions.	No specific costs are added to those required for routine maintenance of the plumbing system.
9.1.12	Sediment accumulation and microbial growth in water stagnated at dead-end branches	B9.1.12a	Plumbing design, installation and renovation done by accredited professionals	P	Prevent the occurrence or correct for no-flow and/or low flow conditions.	Assure proficiency of plumbing design, installation and renovation professionals by requiring them to be accredited for those jobs (WHO, 2006).	Risk reduction is effective.	No extra investment-costs are required. Moderate to high in case of redesign.	No specific costs are added to those required for routine maintenance of the plumbing system.

Hazardous event (ref. from THDB)		Risk reduction option/Barriers			Strategy and some examples on methods from the literature			Costs (reference)	
(no.)	**(description)**	**Ref.**	**Option**	**Type**	**Strategy (reference)**	**Method (reference)**	**Effectiveness (reference)**	**Investment**	**Operation and maintenance**
9.1.13	Iron corrosion from iron/steel pipes	B9.1.13a	Pipes lining with epoxy or polyurethane	P	Eliminate the release of corrosion-particles from iron pipes.	Replacement or lining of iron pipes.	Risk reduction is effective.	Moderate to high depending on existing conditions.	No specific costs are added to those required for routine maintenance of the plumbing system.
9.1.14	Water hammer, high velocities and/or turbulence or cavitation	B9.1.14a	Plumbing design, installation and renovation done by accredited professionals	C	Eliminate noisy flow conditions (Houten, 2006)	Assure proficiency of plumbing design, installation or renovation professionals by requiring them to be accredited for those jobs (WHO, 2006)	Risk reduction is effective.	No significant investment costs are required.	No specific costs are added to those required for routine maintenance of the plumbing system.
9.1.15	Microbial growth due too long residence time of water, warm temperatures, sediment accumulation or exposition of the water to light	B9.1.15a	Do not store drinking water	C	Eliminate or mitigate microbial growth in household storage tanks.	Do not store water at domestic premises (Nath et al., 2006).	Risk reduction is effective.	No significant investment costs are required.	No specific costs are added to those required for routine maintenance of the plumbing system.
		B9.1.15b	Tank made of approved materials and periodically sampled to ensure the microbiological quality of the stored water	P	Eliminate or mitigate microbial growth in household storage tanks.	Household storage tanks materials (e.g., opaque) and dimensions (water residence times) not promoting microbial growth. Careful hygiene and control of the stored water microbiological quality (Nath et al., 2006).	Risk reduction is moderate to effective.	No significant investment costs are required.	No specific costs are added to those required for routine maintenance of the plumbing system.
9.2 Hot water plumbing system									
9.2.1	Microbial growth in hot water system (heaters, storage tanks, pipes, taps and shower heads) with water below 50 ºC	B9.2.1a	Keep an effective concentration of disinfectant residual	P	Inhibit microbial regrowth in hot water systems.	Keep water at ca. 50ºC. Maintain an effective concentration of disinfectant residual (US CDC, 2006; WHO, 2006)	Risk reduction effect dependent of the water characteristics (e.g., AOC).	No investment costs are required.	No specific costs are added to those required for routine maintenance of the plumbing system.

Hazardous event (ref. from THDB)		Risk reduction option/Barriers			Strategy and some examples on methods from the literature			Costs (reference)	
(no.)	**(description)**	**Ref.**	**Option**	**Type**	**Strategy (reference)**	**Method (reference)**	**Effectiveness (reference)**	**Investment**	**Operation and maintenance**
9.2.2	Scaling build-up leads to reductions in heater/tank heating efficiency, storage capacity and lifetime	B9.2.2a	Proper equipment selection and maintenance	P	Use of equipment not prone to scaling. Regular decalcification of the heater parts in contact with water. Provide that heater inlet water has no excessive hardness.	Heater characteristics providing minimization of scaling development in the water tank. Proper maintenance of the heater. Hardness removal at the treatment plant or at the point-of-entry (US CDC, 2006; WHO, 2006).	Risk reduction is moderate to effective.	Low to high costs, depending on the existing conditions.	Operation and maintenance costs are low to moderate, depending on the existing conditions.
9.2.3	Water from shower or bath taps supplied above 55ºC.	B9.2.3a	Installation of thermostatically controlled taps or mixer taps (bath and shower)	C	Prevent scalding water to contact consumers body.	Use devices blocking the release of water above 55ºC from taps. (US CDC, 2006; WHO, 2006)	Risk reduction is effective.	Low costs are required.	Low costs are required.
9.3 Point-of-Entry and Point-of-Use treatment devices									
9.3.1	Fouling of treatment devices by suspended solids, iron, manganese or copper	B9.3.1a	System selection, design, installation and maintenance by competent/accredited professionals	P	Use of appropriate treatment technology and equipment.	To ensure proficiency in equipment selection, design, installation and maintenance, these tasks are developed by licensed professionals (USEPA, 2006).	Risk reduction effect depends on the specificity of water characteristics.	Low to moderate costs, depending on the existing conditions.	Low to moderate costs, depending on the water characteristics.
		B9.3.1b	Treatment devices equipped with warning systems to alert users when the head losses reach a predetermined threshold	C	Prevent equipment malfunctioning / failure due to fouling.	Use devices to automatically alert of equipment fouling acceptable threshold (USEPA, 2006).	Risk reduction is effective.	Low investment costs.	Low operation and maintenance costs.
9.3.2	Inadequacy of the treatment process for a targeted compound (e.g., hard water lead removal by cation exchange; arsenic removal by granular activated carbon filters)	B9.3.2a	System selection, design, installation and maintenance by competent/accredited professionals	P	Use of appropriate treatment technology and equipment.	To ensure proficiency in equipment selection, design, installation and maintenance, these tasks are developed by licensed professionals (USEPA, 2006).	Risk reduction effect depends on the specificity of water characteristics.	Low to moderate costs, depending on the existing conditions.	Low to moderate costs, depending on the water characteristics.

Hazardous event (ref. from THDB)		Risk reduction option/Barriers			Strategy and some examples on methods from the literature			Costs (reference)	
(no.)	(description)	Ref.	Option	Type	Strategy (reference)	Method (reference)	Effectiveness (reference)	Investment	Operation and maintenance
9.3.3	Failure of the contaminant removal process (e.g., exhaustion of the resin or carbon adsorptive capacity; UV lamp bulb/housing opaqued by dirt)	B9.3.3a	Devices equipped with warning systems to alert consumers when the contaminant(s) removal becomes unsatisfactory. Whenever justified by the involved risks significance, the systems may comprise shut-off mechanisms which will automatically stop water flow upon treatment failure	C	Prevent equipment unacceptable decreases in treatment efficiency.	Use devices to automatically alert for unsatisfactory efficiency (USEPA, 2006).	Risk reduction is effective.	Low investment costs.	Low operation and maintenance costs.
9.3.4	Enhanced corrosion of plumbing system and appliances materials (e.g., lead, copper) due to excessive water softening	B9.3.4a	System selection, design, installation and maintenance by competent/accredite d professionals	C	Use of appropriate treatment technology and equipment.	To ensure proficiency in equipment selection, design, installation and maintenance, these tasks are developed by licensed professionals (USEPA, 2006).	Risk reduction is effective.	No investment costs required.	No operation and maintenance costs required.
9.3.5	Backflow of liquid waste streams (e.g., from reverse osmosis, ionic exchange resins) or backwash water (from adsorptive media filters) to the treated water lines	B9.3.5a	System selection, design, installation and maintenance by competent/accredite d professionals. Monitoring of the treated water chemical quality.	P/C	Absence of cross connections with the treatment lines (USEPA, 2006).	To ensure proficiency in equipment selection, design, installation and maintenance, these tasks are developed by licensed professionals (USEPA, 2006).	Risk reduction is effective.	No investment costs required.	No operation and maintenance costs required.

Hazardous event (ref. from THDB)		Risk reduction option/Barriers			Strategy and some examples on methods from the literature			Costs (reference)	
(no.)	**(description)**	**Ref.**	**Option**	**Type**	**Strategy (reference)**	**Method (reference)**	**Effectiveness (reference)**	**Investment**	**Operation and maintenance**
9.3.6	Growth/release of microorganisms from treatment devices (e.g. granular activated carbon/GAC filters)	B9.3.6a	Use of post contactor disinfection (e.g. UV). Regular analysis of the microbiological safety of the treated water	C/P	Avoid microbial accumulation / release from contactors (e.g., GAC, resins). Prevent the passage of released hazardous-microorganisms to the internal system.	Proper operation and maintenance of contactors. Use of post contactor UV disinfection. Monitoring of the microbiological quality of the treated water (USEPA, 2006).	Risk reduction is effective.	Moderate investment costs.	Low operation and maintenance costs.
9.3.7	Unsafe handling or storage of strong caustics/acids used for adsorptive media regeneration	B9.3.7a	Adsorptive media regeneration exclusively made by competent/certified professionals	C	Prevent the occurrence of accidents due to unsafe handling / storage of chemicals.	Regeneration of contactors bed made by proficient / certified professionals (USEPA, 2006).	Risk reduction is effective.	No investment costs required.	No extra operation and maintenance costs required.
		B9.3.7b	Do not store regeneration chemicals locally	C	Prevent the occurrence of accidents due to unsafe handling / storage of chemicals.	Offsite regeneration of contactors. Do not store caustics / acids locally (USEPA, 2006).	Risk reduction is effective.	No investment costs required.	No extra operation and maintenance costs required.