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Risk assessment case study

Bergen, Norway

TECHNEAU

Risk assessment case study – Bergen, Norway

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Risk assessment case study – Bergen

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Summary

The report provides an overview of the application and results of a risk and vulnerability analysis (RVA) (in Norwegian: ROS- analyse) of Bergen's water supply system covering all elements from source to tap (i.e. catchment, source, treatment plant, and distribution). The analysis gives an overview of the risk-picture for the water supply system. The main conclusion is that the flexible and redundant water system of Bergen, where 5 independent waterworks feed water into the same system, reduces the consequences from many of the undesired events which might happen. This puts Bergen in a unique situation compared to many other water companies in Norway. However, resulting from the analysis, we have identified new possible risk reducing measures for all elements in the water supply system which will improve the safety of the system to an even higher level. Within the project, a new procedure for assessing the strength of the hygienic barriers, represented by the water treatment step and the disinfection step, has been developed. By using large datasets from the SCADA-system, long time-series of water quality data has been aggregated into easy understandable risk measures represented by duration curves. The risk analysis is organised and carried out within a database system, making it easy to update and improve the analysis at later stages.

Contents

1 Introduction

1.1 Background

Within Work Area 4 (WA4) *Risk Assessment and Risk Management*, in the TECHNEAU project, six risk assessment case studies were carried out at different drinking water systems during 2007-2008. The aim of the case studies was to apply and evaluate the applicability of different methods for risk analysis (i.e. hazard identification and risk estimation) and to some extent risk evaluation of drinking water supplies. The case studies will also provide a number of different examples on how risks in drinking water systems can be analysed and evaluated. The drinking water supplies in the following six locations constitute the case study sites where risk assessments were performed in WA4:

a) Göteborg, Sweden
b) Bergen, Norway
c) Amsterdam, the Netherlands
d) Freiburg-Ebnet, Germany
e) Březnice, Czech republic
f) Upper Nyameni, Eastern Cape , South Africa

The present report presents a risk assessment of the drinking water system in Bergen, Norway. This case study is conducted by Jon Røstum and Bjørnar Eikebrokk in collaboration with Water and Wastewater Department, City of Bergen.

1.2 Objectives and scope

The main objective of this paper is to provide an overview of the application and results of a Risk and Vulnerability Analysis (RVA) (in Norwegian: ROS-analyse) of the Bergen water supply system. The risk and vulnerability analysis of the Bergen water supply system is a response to the results from the internal and external evaluations after the waterborne *Giardia*- outbreak occurring in Bergen in 2004 where up to 6000 persons were infected. The incident was the first documented disease outbreak from waterborne protozoan pathogens in Norway. One of the recommendations from the external evaluation committee was to perform a risk analysis covering all elements from source to tap in the water supply system. After the outbreak the municipality has focused on proactive risk management of the complete water supply system, from source to tap.

In this case study, a description of the method for risk and vulnerability analysis is described together with some of the interesting findings from the analysis which can be of interest for a broader audience. For a more detailed overview of the analysis, we refer to the complete report (Røstum and

Eikebrokk, 2008) which also is available for download from the homepage of Bergen Water/Bergen municipality.

The most important results for Bergen municipality will be a list of potential hazardous events and corresponding risk reduction options including suggestions for critical control points (CCP). The hazardous events are evaluated with respect to probability and consequence, and they are listed for all elements from source to tap.

1.3 Method

The method for carrying out the risk and vulnerability analysis is based on a modification of the existing Norwegian guidelines for risk and vulnerability analysis (RVA)[1] in water supply systems (Norwegian Food and Safety Authority, 2006), but also some elements from WHO's Water safety plans (WSP) and the HACCP principles are implemented in the analysis. The main focus is on identifying hazardous events, a risk evaluation matrix, and identifying risk reduction options and control points.

Figure 1 illustrates the concept of hygienic (safety) barriers in a water supply system considering all elements from source to tap. Within the project a partly quantitative and qualitative analysis of the strength of these barriers has been carried out.

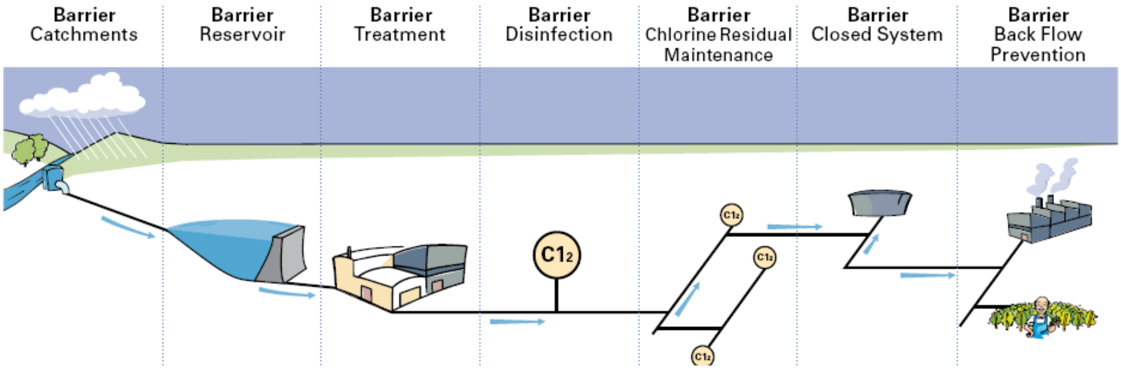

Figure 1 Illustration hygienic barriers in a water supply system from source to tap (modification of a figure taken from: SA Water - Drinking water quality report 2004-2005)

Figure 2, which due to its shape is called a bow-tie diagram, illustrates the concept of risk and vulnerability analysis with identification of threats, undesired event, chain of causes and consequences. Different types of safety barriers (e.g. hygienic barriers) exist for reducing probability of the events and/or reducing the resulting consequences from an event.

[1] The Norwegian term "RVA" might be interpreted as the same technique as what in Techneau is called a Coarse Risk Analysis (CRA). However since the Norwegian term is most commonly used in Norway the term RVA is used in this report.

With reference to Figure 2 we asked the following questions for the Bergen water supply system:

- What can go wrong in the water supply system in Bergen?
- How likely are these events to occur?
- What are the resulting consequences?
- Which safety barriers exist? (for both left and right side of Figure 2)
- How strong are the existing safety barriers?
- What is the corresponding risk for each event?
- Which new safety barriers/risk reducing measures (e.g. control, education, physical) can be implemented?

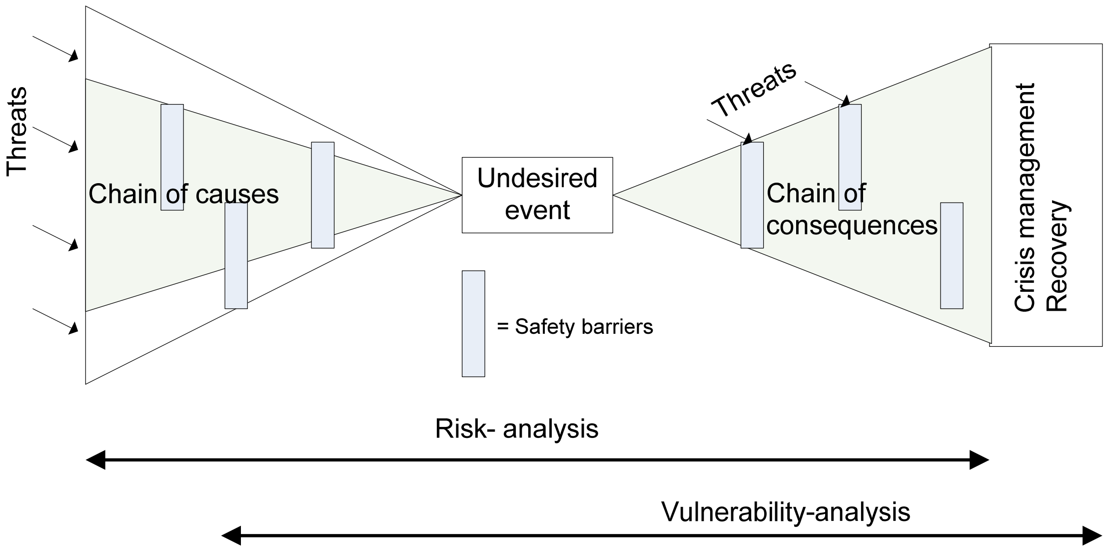

Figure 2 Illustration of risk and vulnerability analysis with identification of threats, undesired event, chain of causes and consequences (inspiration from Rausand, 2006).

For organising the risk registering process a database-tool has been developed. The user-interface of the tool is shown in Figure 3. As an integrated part of the tool a coding system for undesired events has been developed covering all elements in the drinking water system. The work with the coding system has been inspired by the hazard database developed in the EU 6FP Techneau project (described in Rosen et al. 2007).

By organizing the risk and vulnerability analysis process and results in a database, we believe will make future updates/modifications of the analysis easier. Hopefully, this will turn the project into something like a *dynamic/living* risk and vulnerability analysis for Bergen Water.

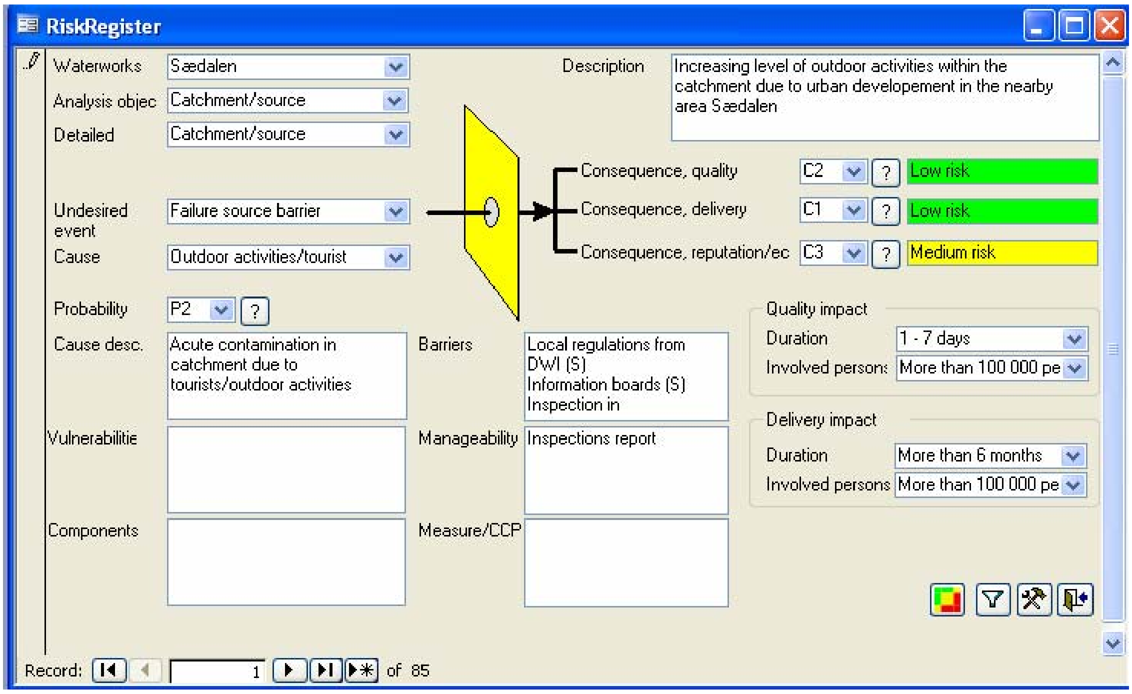

Figure 3 User interface for registering undesired events and for organising the risk assessment process.

1.4 Limitations

The analysis focuses on the all elements in the water supply system, from source to the distribution system. In Norway the service connection from the property to the distribution pipe is private, i.e. the municipality is not the owner and therefore not responsible for these pipes. Private service connections are therefore in general not included in the analysis, but aspects on the private system which might have consequences on the public water supply system (e.g. backflow prevention from properties) are included in the analysis.

The analysis has an "all hazard approach", however focusing on safety (health) issues and less on security issues. Organisational risks (e.g. risk related to restructuring the water company and internal processes) are not covered.

2 System description

Bergen is the second largest city in Norway with a population of approximately 250 000. The water supply system is owned by the municipality and operated by a public water company, Bergen Water KF, which is 100% owned by the municipality.

One important year in the water history of Bergen is the year 1972 when the old Bergen municipality and 4 surrounding municipalities merged and formed the "new" Bergen municipality. This resulted in a water company with as much as 18 larger and smaller water works with low quality and vulnerable sources. The Master Plan of 1989 drew up some major lines to increase water supply safety, and Bergen decided to follow two major strategies:

- Reduce the number of water works by building 5 larger water treatment plants
- Establishing a common water distribution network

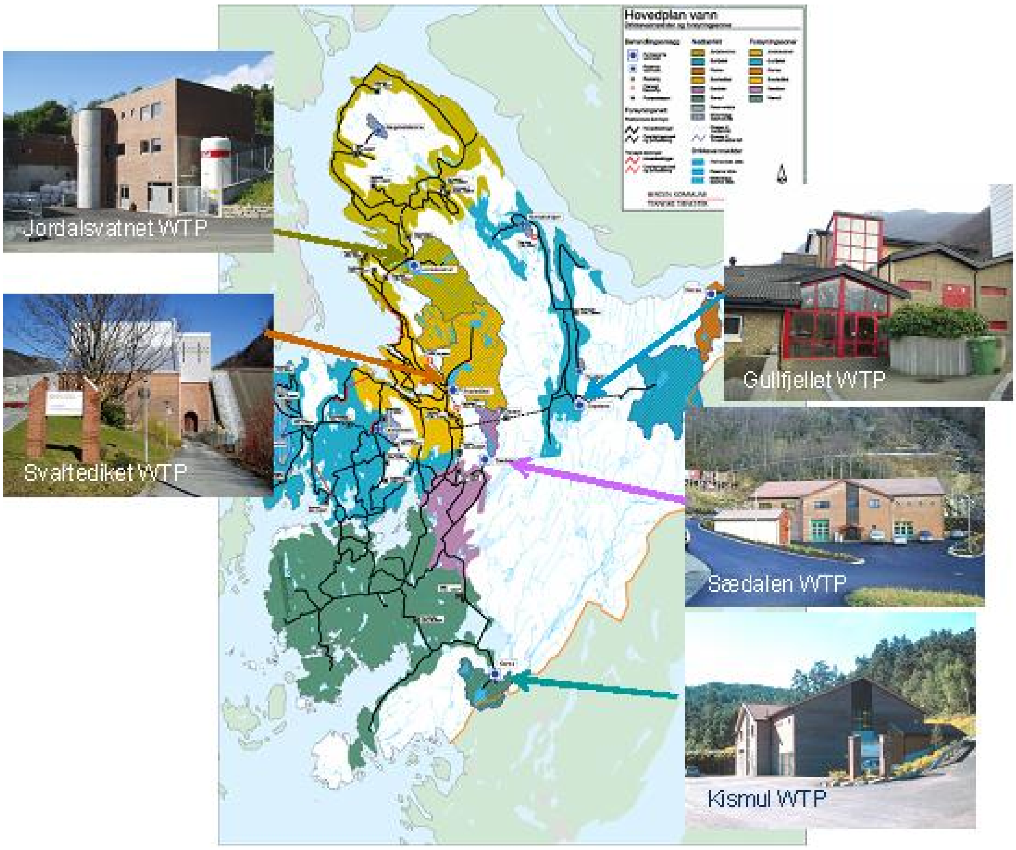

Figure 4 Overview of the water supply system in Bergen

By 2008, the City of Bergen had two small water works and the major Bergen Water Works supplying 235.000 inhabitants (96% of the population) in Bergen. The Bergen Water Works has 5 water treatments plants which produce water into a common distribution system. Each water treatment work has its primary supply zone, but the supply zones can now be interconnected. Figure 4 gives an overview of the water supply system in Bergen by the year 2008.

2.1 Source water

All catchment areas are claused and activities like bathing, fishing, camping, use of boat and horse riding is prohibited. Four water works are well protected with watersheds and water sources in mountainous areas, without buildings, sewage pipes, waste water treatment plants and agricultural activities. Thus, possible contamination sources are limited to wild animals and birds, grazing sheep and recreation activities.

Figure 5 gives the overview of the catchment for one of the major water treatment plants, Jordalsvatnet WTP.

Figure 5 Overview Lake Jordalsvatnet (catchment zone and source).

2.2 Treatment

Four of the five water treatment plants employ similar treatment technologies consisting of coagulation, direct filtration and disinfection. Four of the WTPs employ coagulation, filtration, corrosion control, and disinfection by UV and/or chlorination. The fifth WTP has no coagulation because the raw water has good/acceptable microbial quality and very low NOM and turbidity levels. The WTPs feed water into the water distribution system at different locations thus creating a flexible and redundant (correct word?)system. Thus, one of the WTPs can be taken out of service at any time; the remaining WTPs have still sufficient capacity to maintain water supply for the entire city.

Figure 6 shows a typical flowchart for the water treatment systems in Bergen. It focuses on the treatment system, but also shows how the water passes from the catchment zone, via source, to the water treatment system, and finally to the distribution network.

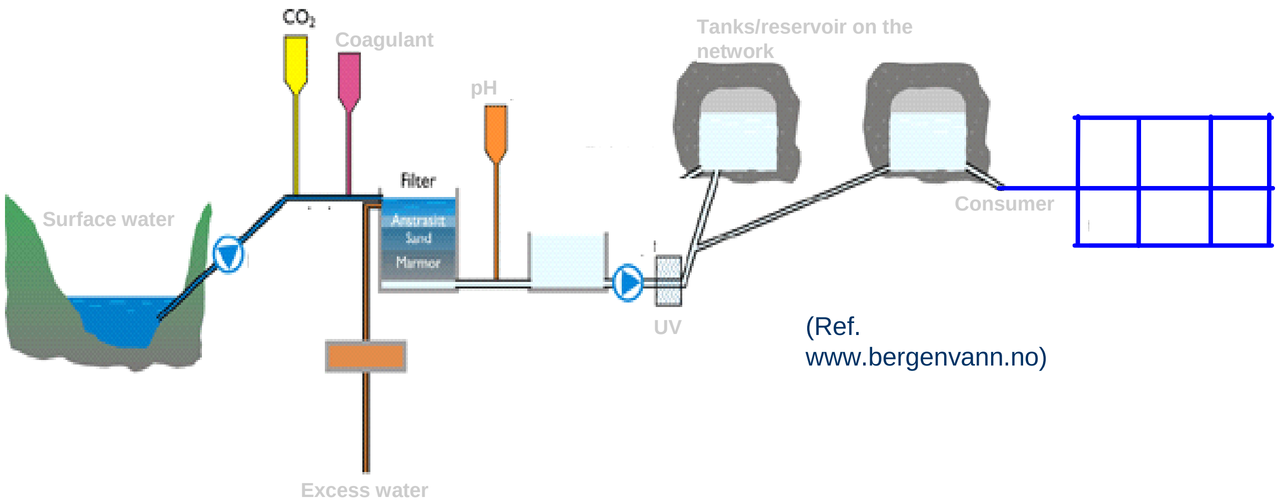

Figure 6 Typical Water treatment, Bergen

2.3 Distribution

The water distribution system consists of:

- 900 km public and approximately 900 km private pipelines
- 65 water reservoirs and 37 water tanks/basins which gives Bergen 282.000 m^3 water reserves covering 2 days of consumption
- 78 pumping stations
- 10.000 manholes and 25.000 valves of different types

2.4 Earlier incidents and problems

In the autumn of 2004 about 1.500 people were diagnosed with giardiasis. It was caused by the parasite *Giardia lamblia*, spread by the drinking water from one of the sources – Lake Svartediket. This was the first documented disease outbreak from waterborne protozoan pathogens in Norway – and it was a large incident also in a European context. The source of the parasites was probably a leaking sewer system from a single house at the border of the watershed.

The accident was followed up both by an internal (Tveit et al, 2005) and an external evaluation (Eikebrokk et al 2006).

3 Risk analysis

3.1 Hazard identification

For identification of hazards an interdisciplinary team with representatives from operator (Bergen Water), owner (Water and wastewater department) and experts from SINTEF were assembled. By using detailed flow-diagrams for the water supply system combined with plenary discussions and onsite inspections, potential hazards were identified. Figure 1 also illustrates the systematic way of dealing with hazard identification for the whole water supply system from source to tap. By using updated flowcharts for each specific water work, a more complete list of possible undesired events was identified. The Techneau hazard database was used as a checklist in the hazard identification process.

All identified hazards (i.e. undesired events) were registered in a database (Figure 3). In total 85 different hazards were identified for Bergen water supply system. However, it should be mentioned that a selection of events has been carried out within the process, leaving out events at low risks.

A coding system was established before entering the different hazards in the database. The hazards were coded in two main groups, i.e. causing failure in the hygienic barrier (water quality) and/or failure in supplying water (quantity). In the following a summary of the identified undesired events is given:

I **Failure in hygienic barriers** (water quality)/induction of contaminated water into network:

- Contamination in water tanks (water surface)
- Induction due to low pressure/non-pressurised network
    - Operational and maintenance situations (e.g. valve operations)
    - Power failure
    - Work on non-pressurised network (e.g. repair, rehabilitation, construction)
    - Fire (huge water demands might lead to low pressure)
    - Water mains failure (might lead to non-pressurised system)
    - Incorrect operation of valves
    - Failure pumping stations in zones without water tanks
    - Water hammer
    - Pipe fracture valve closes without intention
    - Water tanks emptied due to communication error
    - Extraordinary water demand/tapping
    - In-pipe processes
- Cross-connection/backflow
    - Unintended backflow from building
    - Sabotage (intended backflow from building)

II Failure water deliverance/quantity:

- Operational and maintenance situations (e.g. valve operations)
- Pipe failures
- Rockslides/rockfall in tunnel
- Water tanks emptied due to communication error
- Failure pumping stations
- Failure equipment (e.g. valves)

3.2 Risk estimation

For each of the identified hazards the corresponding probabilities and consequences are estimated. The resulting risks are presented as standard risk matrixes. The *probabilities* and *consequences* are given in terms of the following categories (Tables 1 and 2):

- *Probability Classes,* from *P1 = Small probability* to *P4 = Very High probability;*
- *Consequence Classes*, from *C1 = Small consequence* to *C4 = Very High consequence*.

Table 1 Criteria for the different levels of probability.

PROBABILITY LEVEL	Criteria
P1: Small probability	a: The event not known within the water industry b: The event can not be totally excluded c: Security evaluation indicates low probability
P2: Medium proability	a: The event has occurred within the water industry the last 5 years b: Professional and precautionary evaluations indicate that the incident might can happen within the next 10-50 years. c: Security evaluation indicates medium probability
P3: High proability	a: The event occurs every year within the water industry Det b: The water company has observed some events or the events has nearly happened c: Professional and precautionary evaluations indicate that the incident might can happen within the next 1-10 years d: Security evaluation indicates high probability
P4: Very high proability	a: The event is regularly observed within the water company b: Security evaluation indicates very high probability

Table 2 Criteria for the different levels of consequence.

Consequence level	Criteria
C1: Small consequence	a: Quality: Quality hardly affected, compliance with drinking water regulations b: Quantity: insignificant influenced c: Reputation & economy: Reputation not threatened or economic loss less than 5 % of annual cost.
C2: Medium consequence	a: Quality: For a short period a minor non-compliance with drinking water regulations b: Quantity: For a short period (hours) interrupted water supply to an area. c: Reputation & economy: Reputation threatened or economic loss less than 5-10 % of annual cost.
C3: High consequence	a: Quality: non-compliance with drinking water regulations, consequences for health b: Quantity: For a long period (days) interrupted water supply to an area. c: Reputation & economy: Reputation lost for a short period or economic loss less than 10-20 % of annual cost
C4: Very High consequence	a: Quality: Serious violation of drinking water regulations, risk for life and health, Norwegian Drinking water regulations § 18 comes into force b: Quantity: For a long period (days) interrupted water supply to for most of the customers c: Reputation & economy: Reputation lost for a long period or economic more than 20 % of annual cost

For some of the undesired events a detailed estimation of the probability and/or the consequences was carried out. In the following chapter a description of the method for calculating the probability of treatment failure based on SCADA data is described.

3.2.1 Procedure for assessment of the probability of failure in the hygienic barrier represented by the treatment step

Within the project a new procedure for assessing the strength of the hygienic barriers (cf. Figure 1 and Figure 2) represented by the water treatment step and the disinfection step has been developed. By using large datasets from the SCADA-system, long time-series of water quality data has been aggregated into easy understandable *duration curve* which can be used for calculating risk measures such as availability and downtime of the hygienic barrier. The availability has been used as estimate for the probability required in the risk analysis.

The "strength" of the hygienic barriers in the water treatment step and the disinfection step has been calculated based on the requirements given in the guidelines for the Norwegian Drinking water regulations (Norwegian Food and Safety Authority, 2005):

- **Turbidity** (% of time where turbidity > 0.2 NTU)
- **UV-dose** (% of delivered water where UV-dose < 40 mJ/cm^2/ or % of time UV-dose <40 mJ/cm^2).

Figure 7 shows an example of a duration curve for a specific filter for 1 month analysis period. The turbidity in the outflow from one filter was less than the threshold value in 58 % of the time, i.e. not fulfilling the requirements in 42% of the time.

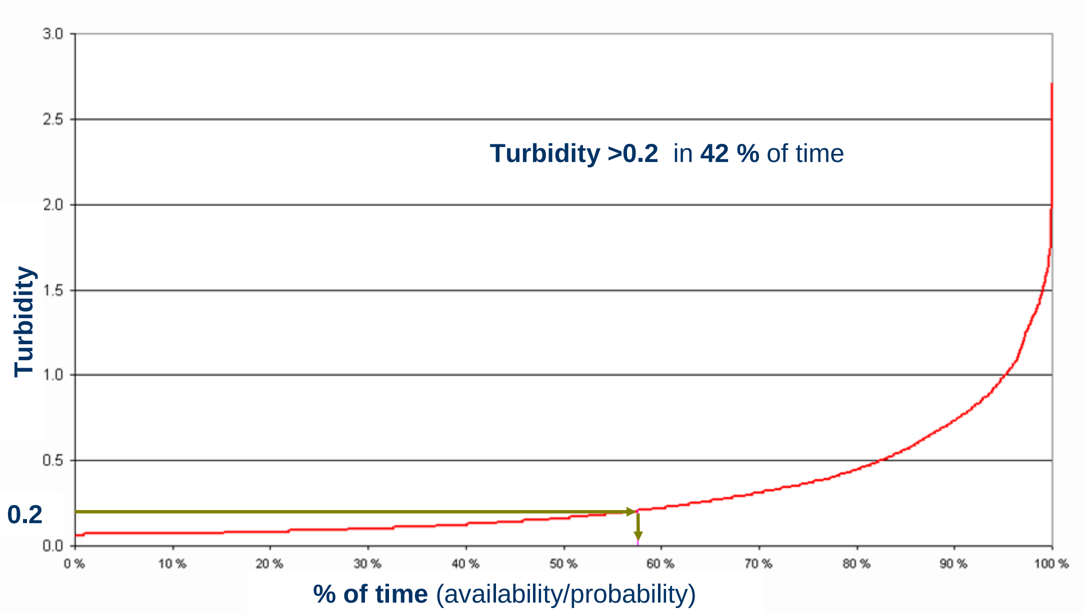

Figure 7 Duration curve for one filter calculated for a period of 1 month in a water treatment plant in Bergen (worst case)

Table 3 shows the complete results for the same water treatment plants in Bergen. The analysis is carried out for 4 parallel filters and also from the outlet of the clean water tank. The analysis has been carried out for both 1 year and 1 month time intervals. The values given in the table can be interpreted as the “strength” of the hygienic barrier represented by the water-treatment step (i.e. coagulation/filtration). There are large differences between the individual filters and also from the outlet of the clean water tank. This illustrates the need for measuring turbidity after each filter (i.e. a critical control point). The length of the time-interval used in the analyses, also have influence on the results. The shorter period analysed, the more likely high values of downtimes can be observed. It should be noted that the situation shown in Table 3 is not representative for the water treatment plants in Bergen as whole, but represent a worst case.

Table 3 Summary data for the strength of the hygienic barrier represented by the treatment-step (i.e. coagulation/filtration)

Period	% of time where the treatment barrier does not fulfil the requirements for turbidity removal				
	Filter 1	**Filter 2**	**Filter 3**	**Filter 4**	**Outlet (from clean water tank)**
1 year	13 %	20 %	13 %	7 %	3 % (> 0.2 NTU)
1 month	24 %	42 %	26 %	14 %	8 % (> 0.2 NTU)

Duration curves have also been generated for UV-disinfection for different water treatment plants in Bergen. Figure 8 shows the duration curve for one specific UV-disinfection unit. In the figure the required threshold value 40 mJ/cm² is indicated for all the 5 parallel aggregates. For this water treatment plant water meters are available for each UV-aggregate making it possible to calculate the duration curve as a function of percentage of delivered water volume where the UV-dose has been lower than the required dose (40mJ/cm²). Alternatively the unit "% of time" could have been used but "% of delivered water" is a better measure,

It should be noted that for the specific time period analysed, the redundant water transport system in Bergen was not fully implemented yet. Due to the important role of this specific treatment plant, water was delivered from the plant even though the UV-dose was lower than the required values. The observed duration curve for this specific UV-plant is therefore *not* representative for the other UV-plants in Bergen. However it illustrates the power of the analysis.

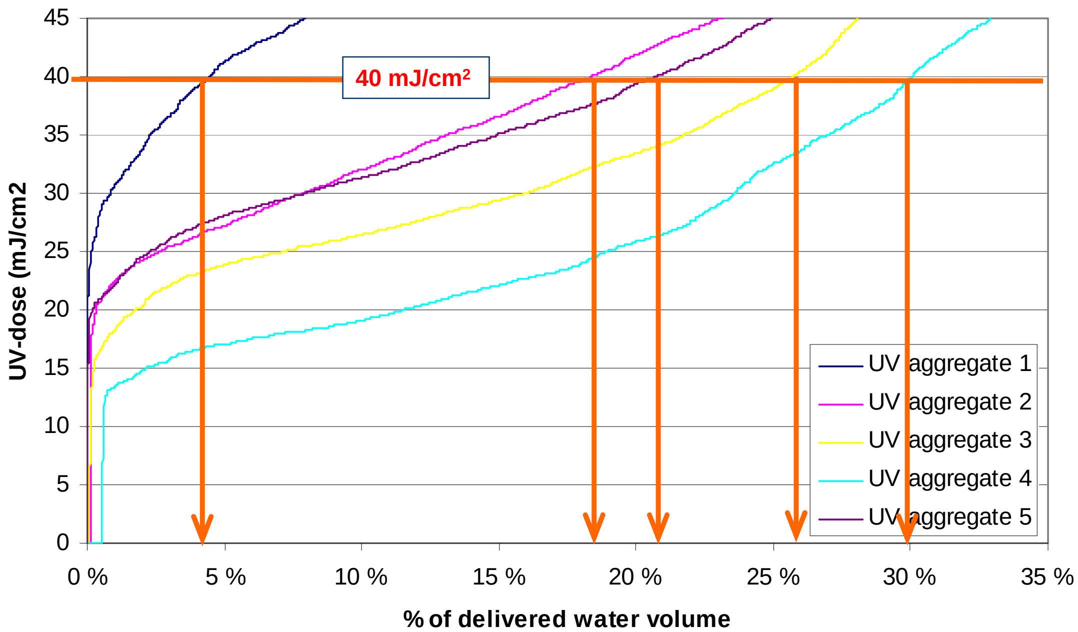

Figure 8 Duration curve (part of) for UV-disinfection in a water treatment plant in Bergen

Similar analysis can be carried out also for other criteria in the drinking water directive, e.g. chlorine residual. An interesting extension of the duration curve concept is also to generate duration curves for failure in water treatment and disinfection at the same time.

3.3 Sensitivity analysis

The matrix based risk and vulnerability analysis is a relatively rough method and a sensitivity analysis is therefore not carried out for this project.

Since the estimation of risk (both probability and consequences) normally is carried out by rough estimates these values might vary according to personal references. If a detailed estimation based on data is available, this will not be the case. However, in reality detailed analysis for estimation of risks is seldom available and possible for all undesired events.

4 Risk evaluation

One outcome of the analysis of a specific hazardous event/undesired event is the *risk*, given by probability of occurrence, *P*, and consequence, *C*. This set (*P*, *C*), is to be inserted in a Risk matrix (see Figure 3) where each event is identified through a coding system covering all undesired events. Three different risk matrixes are generated, one for *water quality* issues, one for *quantity/delivery* and one for *loss of reputation/economy*. Separate evaluations are carried out for each of these (see Figure 9). The numbers in the figures are not supposed to be read.

Riskmatrix quantity	**Riskmatrix water quality**	**Riskmatrix loss of reputation/economy)**
		

Figure 9 Illustration of the 3 different risk matrixes covering the issues: water quality, quantity/delivery and loss of reputation/economy.

For events in the red area (both high probability and consequences), control measures have to be initiated; for events in the yellow area (medium probability and consequences), it is required to search for cost-effective risk reducing measures.

Some of the events might lead to consequences with both water quality and water quantity issues. For each of undesired events possible risk reducing measures have been identified.

4.1 Risk reduction options

For failures in the hygienic barrier represented by the distribution system the two following main drivers must be present in order to have contamination:

- Low pressure/non -pressurised system *and*
- Contamination agents nearby/available

Possible risk reducing measures for improving the hygienic barrier in the network can therefore be aimed at both of these aspects.

Some geographical areas are more likely to have induction of contaminated water than others. For identification of these areas systematic analysis like fire flow analysis and network reliability analysis can be carried out as an action resulting from the risk and vulnerability analysis. Fire flow analysis identifies areas with low water pressure in case of large fire water outlets. Network reliability analysis identifies pipes, which in case they break/fail, have consequences for the rest of the water network (water quantity). Such pipes failures might also lead to non-pressurised system and possible induction of contaminated water. Analysis like fire flow and reliability analysis can be used as one criterion for assessing the "strength" of the hygienic barriers in the distribution system. However, such analyses should be followed up with physical improvements (rehabilitation, new constructions, change in topology etc) in order to have effect on the safety of the system.

Within the project it was not possible to include a hydraulic reliability analysis of the network as illustrated in Figure 10. The output from such analysis might be used for identification of the most critical pipes in case of pipe failures.

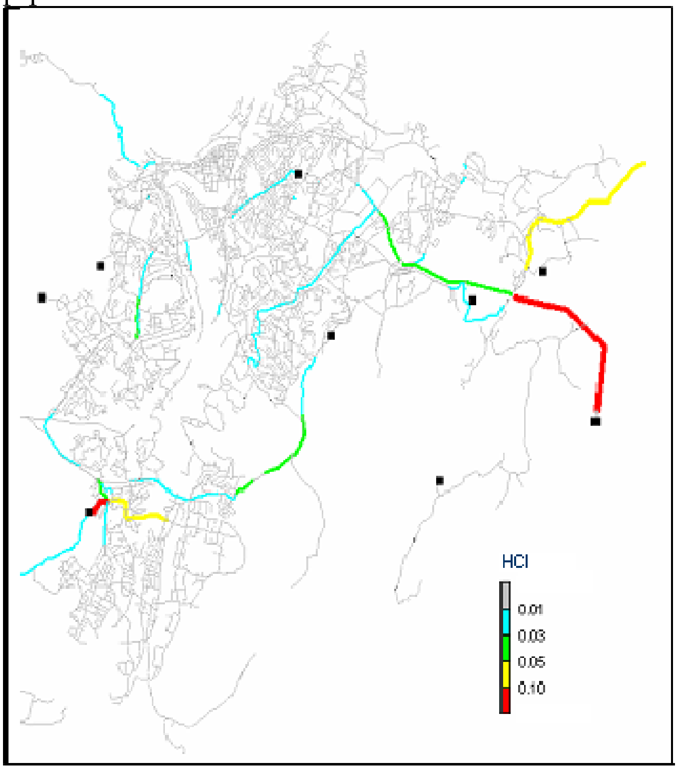

Figure 10. Critical pipes for the whole water distribution system (example).

According to Bergen Water's existing master plan (2005-2015) for water supply, the annual rehabilitation rate is fixed to 1%. However the city council has indicated that they might increase this up to 2 % per year. Even though these numbers for are relatively rough for the rehabilitation needs, it illustrates the high level of ambition Bergen Water/Bergen city council have for safeguarding the water supply.

5 Discussion and conclusions

5.1 Method evaluation

The method applied for evaluating the risk and vulnerability of the water supply system in Bergen is a relatively rough method which gives the overview of the overall risk picture of the water supply system covering all elements from source to tap (i.e. catchment, source, treatment plant, and distribution). For assessing the probabilities and consequences for the different undesired events, rough estimates might be applied but the analysis can also be made more detailed by applying separate tools/methods where appropriate.

Table 4 shows a summary of the method evaluation considering different criteria.

The risk and vulnerability analysis can also form the basis for more detailed analysis in specific areas.

Table 4. Summary of the method evaluation by means of different criteria

Criteria	Low	Medium	High
Resources needed			
Required level of expertise needed		X	
Time required for analysis		X	
Required level of data details needed	X		
Method properties			
Ability to consider a source-to-tap approach			X
Ability to include water quantity aspects			X
Ability to consider water quality aspects			X
Ability to consider interactions between events, i.e. chains of events		X	
Ability to acknowledge system structure/design		X	
Ability to consider uncertainties of e.g. probabilities	X		
Ability to consider/model risk reduction options	X		
Ability to be integrated in the water company management/maintenance routines			X
Updating possibilities, i.e. update when new information becomes available			X
Results			
Ability to provide understandable results to the specific end-user			X
Ability to provide input data to be used in further studies, e.g. more detailed risk analysis			X

5.2 Lessons learned

In the following some of the key lessons learned resulting from the analysis are given:

- For carrying out a risk and vulnerability analysis for a water supply system covering all elements from source to tap it is important to include a multidisciplinary team covering all disciplines from source to tap
- It might be useful to include in the team also experts covering generic risk methods. This knowledge is valuable for the working process.
- Top leaders in the water company should be involved in the risk and vulnerability assessment process for anchoring the project in the organisation and also providing the analysis with valuable updated information.
- In this specific project we established a reference group which followed the project tightly. Besides representatives from the water companies (both owner and operator) this group also included experts from health authorities and a local representative from the local office of the drinking water inspectorate (Norwegian Food and Safety Authority). The risk and vulnerability analysis project therefore also served the purpose of information sharing between different stakeholder involved in the work of safeguarding the water supply in Bergen.

5.3 Conclusion

The main conclusion is that the flexible and redundant water system of Bergen, where 5 independent waterworks feed water into the same system, reduces the consequences from many of the undesired events which might happen. This puts Bergen in a unique situation compared to many other water companies in Norway. However, resulting from the analysis, we have identified new possible risk reducing measures for all elements in the water supply system which will improve the safety of the water supply system to an even higher level. Within the project a new procedure for assessing the strength of the hygienic barriers represented by the water treatment step and the disinfection step has been developed. By using large datasets from the SCADA-system, long time-series of water quality data has been aggregated into easy understandable risk measures represented by duration curves. The risk analysis is organised and carried out within a database system, making it easy to update and improve the analysis later.

Bergen water has after the project implemented the duration curve are now being implemented into the SCADA system making it easy to assess the values. We believe the concept of duration curves and the corresponding risk measure is a powerful tool for all actors involved in safeguarding the water quality (owner, operator and inspectorate). Values from this analysis can also be used for benchmarking, both internal within the water company to improve the performance but also external to be compared with others.

The results from the duration curves can also be used for internal benchmarking in Bergen Water for improving the performance (thereby also the hygienic safety) for each filter/UV-aggregate and for the whole treatment plant.

Based on the risk and vulnerability analysis a wide variety of results are available, e.g.:

- A database with identified undesired events with corresponding risk assessment. This also includes a coding system registering hazardous events/undesired events. Totally 85 undesired events are identified. In order to limit the number of events in the database, we discarded many events with low probability and low consequences during processing the data.
- In addition to the information recorded in the database the complete report (Røstum and Eikebrokk 2008) also includes a more thoroughly description of the water supply system possible event.
- New procedures for assessing the strength of hygienic barriers in treatment and disinfection
- Identification of possible risk reducing measures

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