



Risk assessment case study

Březnice, Czech Republic

TECHNEAU

Risk assessment case study – Březnice, Czech Republic



© 2008 TECHNEAU

TECHNEAU is an Integrated Project Funded by the European Commission under the Sixth Framework Programme, Sustainable Development, Global Change and Ecosystems Thematic Priority Area (contractnumber 018320). All rights reserved. No part of this book may be reproduced, stored in a database or retrieval system, or published, in any form or in any way, electronically, mechanically, by print, photoprint, microfilm or any other means without prior written permission from the publisher

Colofon

Title

Risk assessment case study – Březnice, Czech Republic

Author(s)

František Kožíšek, Daniel Weyessa Gari, Petr Pumann, Jan Runštuk,
Jaroslav Šašek (SZU),
Ladislav Tuhovčák, Jan Ručka, Václav Papírník (VUT)

Quality Assurance

Sebastian Sturm (TZW)

Deliverable number

D 4.1.5e

This report is:

PU = Public

Summary

There have been six risk assessment case studies carried out at different drinking water systems during 2007-2008 within the Work Area 4 (Risk assessment and Risk management) of the TECHNEAU project (www.techneau.eu). The main objective of these case studies was to implement and testify the applicability of different methods for risk analysis.

This case study report presents a risk assessment of the drinking water system in Březnice town, the Czech Republic. Březnice is located in central Bohemia, 80 km Southwest of Prague, with a population of 3500. Total drinking water production in the system is 380-520m³/day. Water is abstracted from three groundwater sources located around the town, water from two sources is treated to remove iron and manganese and disinfected with chlorine gas; water from another source is only disinfected with sodium hypochlorite.

The risk analysis in this case study covers the system from source to service connection and was focused on identification of all hazardous events which may influence the quality of distributed water, either in terms of non-compliance with national drinking water quality standards or risks to compromise consumer's health, satisfaction or confidence.

This case study applies the CRA (Coarse Risk Analysis) method for risk identification and estimation process. The basis for the CRA is a description of the water supply system and a list of hazards and related undesired events that may occur in the system. For each event, the likelihood (probability) and consequence (impact) have been assessed using a scale of 5 categories. The consequent risk for each hazard (hazardous event) is expressed as extreme, high, moderate, or low through a combination of the probability and the consequence of each hazard (event) by use of a risk matrix.

To assess supply reliability (in a selected part of the system – the reservoir) the Preliminary Hazard Analysis (PHA) and consequently the FMEA/FMCA methods have been used.

There have been 47 different hazardous events identified and evaluated, 25 for the sources, 11 for the treatment process (and building), and 11 for the distribution system. 44 hazardous events have been further classified and expressed as "extreme risk" (1), "high risk" (15), moderate risk" (16) and "low risk" (12). As the water utility has not developed any own specific risk tolerability criteria, it was agreed within the Water Safety Plans team that both extreme and high risks would be considered as unacceptable, and therefore, risk reduction options will be developed for all extreme and high risks identified, while all low risks would be considered as acceptable. Regarding the moderate risks it was agreed to apply the ALARP (As Low As Reasonably Practicable) principle, i.e. the necessity of risk reduction options for these risks would be discussed on a case by case basis. Some of these risks may be accepted if it is economically and/or technically unreasonable to reduce them, but a monitoring option for such risks should be suggested.

The CRA (Coarse Risk Analysis) method used in this case study seems to be a suitable tool for risk identification and estimation in small water supplies. It may be completed or replaced by a more sophisticated method at a later stage, but for the initial risk assessment process it represents a reasonable approach due to expertise, technical and financial requirements on the one side, but with sufficient sensitivity on the other.

Contents

	Summary	1
	Contents	3
1	Introduction	4
1.1	Background	4
1.2	Objectives and scope	5
1.3	Methodology	5
1.3.1	Hazard identification	6
1.3.2	Estimation of risk: CRA	6
1.3.3	Estimation of risk: FMEA / FMECA	8
1.4	Limitations	10
2	System description	12
2.1	Source water	2
2.2	Treatment	3
2.3	Distribution	4
2.4	Earlier incidents and problems	6
3	Risk analysis	7
3.1	Hazard identification	7
3.2	Risk estimation	8
3.3	Sensitivity analysis	9
4	Risk evaluation	10
4.1	Risk tolerability	10
4.2	Risk reduction options	10
5	Discussion and conclusions	11
5.1	Methods evaluation	11
5.2	Lessons learned	12
5.3	Conclusion	13
6	References	14
	Appendix A – List of identified hazards by CRA method	15
	Appendix B – List of identified hazards by FMEA/FMECA method	26

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 (Fig. 1).

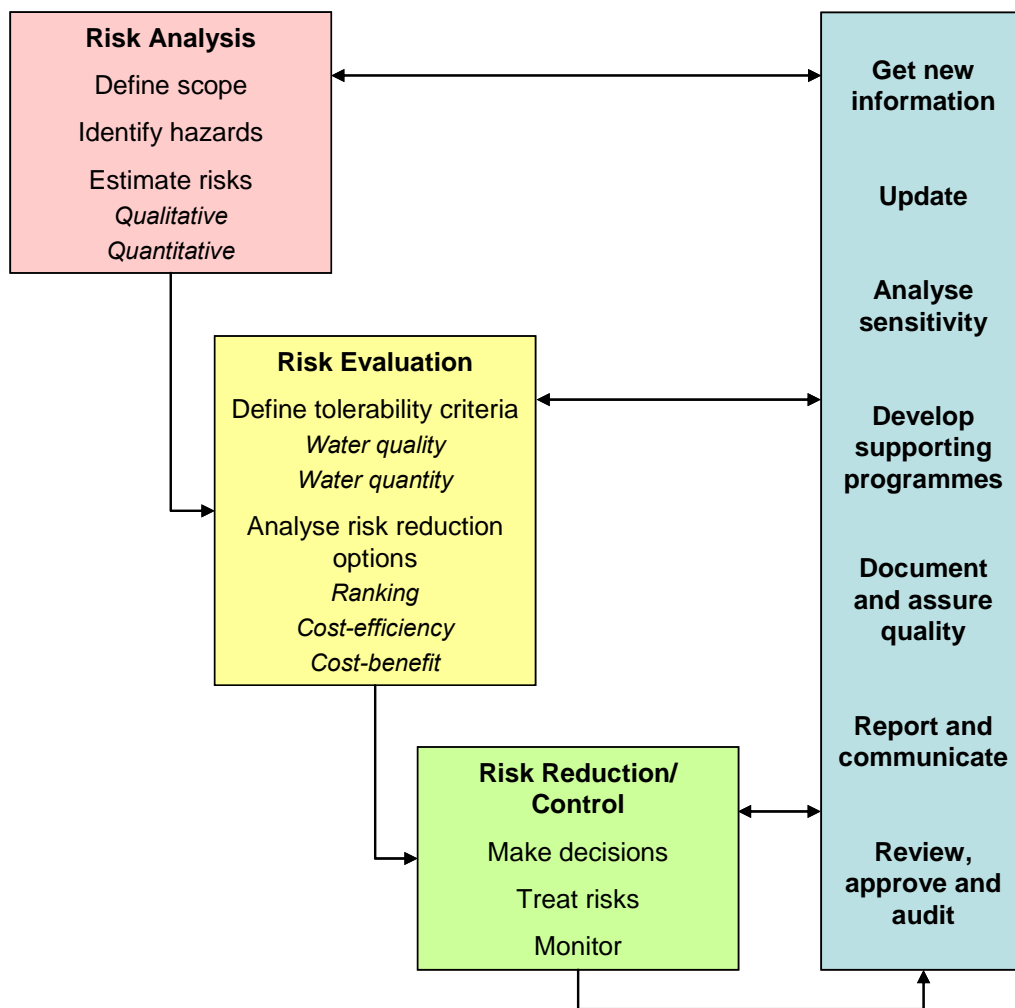


Fig. 1. The main components of the TECHNEAU generic framework for integrated risk assessment in WSP (Rosén et al., 2007).

The case studies also provided 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 constituted the case study sites where risk assessments have been 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 Březnice, Czech Republic. This case study was conducted by the National Institute of Public Health (SZU) in collaboration with VAK Beroun, the local water utility, and the Brno University of Technology (VUT).

1.2 Objectives and scope

The present risk assessment in Březnice water supply was focused on the identification of all hazardous events which may occur within the whole system (from sources to service connections) and which might influence the quality of distributed water, either in terms of non-compliance with national drinking water quality standards or the danger of compromising consumer health, satisfaction or confidence. Part of the system has also been tested due to vulnerability of physical interruption of the supply, i.e. the issue of water quantity. Hazardous events found have been evaluated in terms of their risk (consequence and probability) and finally categorized according to their priority.

There were three main objectives of this study:

- a) This was the first attempt to prepare a water safety plan in the Czech Republic and therefore this work served as a pilot or model example for further applications.
- b) To evaluate the applicability of the TECHNEAU Hazard Database, and some selected methods for risk assessment specified in section 1.3.
- c) To provide objective information on priority risks and investments needed, and hereby support negotiation between operator (VaK Beroun) and owner of the infrastructure (municipality of Březnice). The operator was and is aware of a number of problems in the supply system, but according to the licence, the operator cannot invest anything into the system, but have to ask the municipality to do so. However, the municipality has other priorities and has invested only inadequate amounts in the system during the last 13 years, because it considered water supply as trouble-free.

1.3 Methodology

The risks in the Březnice drinking water supply system have been analysed on an integrated “from source to tap” basis, following the approach established by the Bonn Charter (IWA, 2004) and the WHO Water safety plans (Davison *et al.*, 2005).

Assembling the water safety plan team was the first step undertaken. It was established during the introductory meeting in April 2007. The team consists

of representatives of the operator (VAK Beroun), the owner of the infrastructure (municipality), the local public health authority, the National Institute of Public Health and the Brno University of Technology.

Description of the system was the second step – see section 2.

1.3.1 Hazard identification

To identify hazards for water quality the following tools have been used:

- the checklist in the form of the TECHNEAU Hazard Database (THDB – available on <http://www.techneau.org>),
- past experience (of the personnel of the water utility and the local public health authority) from the past,
- brainstorming,
- the checklist of main hazards for small water supplies developed by the Swiss Gas and Water Association (SVGW, 2003), which lists about 50 examples of hazards for catchment areas and protected zones arising from construction, waste water, agriculture, traffic installation, natural conditions or third-party use, and almost 30 hazards for water collectors, storage, and the distribution network.

1.3.2 Estimation of risk: CRA

To estimate the risk from the hazards identified, kind of the Coarse Risk Analysis (CRA) has been applied. The basis for the CRA is a description of the water supply system and a list of undesired events that may occur in the system. For each event, the probability of occurrence and the consequences are assessed in order to estimate the risk. The objectives of the analysis are to identify undesired events, to rank the undesired events with respect to risk and to assess the need for risk reducing measures.

The probabilities of occurrence are typically defined as small, medium, large or very large. Similarly, the consequences are described as small, medium, large and very large. The risk is expressed as a combination of the probability of occurrence and the consequence of each event by use of a risk matrix (Techneau, 2007).

The probabilities and consequences ranking and the risk matrix, we used in our study, was based on Risk Management Standard AS/NZS 4360 as presented in the WHO monograph on Water safety plans (Davison, 2005, Tables 5.1 and 5.2, page 43) and summarised in Tables 1 and 2 below.

Table 1: Definitions for likelihood (probability) and consequence (impact) categories used for risk estimation.

Level	Descriptor	Description
Likelihood		
A	Almost certain	Once a day
B	Likely	Once per week
C	Moderate	Once per month
D	Unlikely	Once per year
E	Rare	Once every 5 years
Consequence/impact		
1	Insignificant	No detectable impact
2	Minor	Minor aesthetic impact causing dissatisfaction but not likely to lead to use of alternative less safe sources
3	Moderate	Major aesthetic impact possibly resulting in use of alternative but unsafe water sources
4	Major	Morbidity expected from consuming water
5	Catastrophic	Mortality expected from consuming water

Table 2: Qualitative risk analysis matrix used in the case study.

Likelihood	Consequences				
	Insignificant	Minor	Moderate	Major	Catastrophic
A (Almost certain)	H	H	E	E	E
B (Likely)	M	H	H	E	E
C (Moderate)	L	M	H	E	E
D (Unlikely)	L	L	M	H	E
E (Rare)	L	L	M	H	H

Risk rating:

- E - Extreme risk, immediate action required;
- H - High risk, management attention needed;
- M - Moderate risk, management responsibility must be specified;
- L - Low risk, manage by routine procedures.

A modified CRA table was used for formal and systematic documentation of the results obtained. While the usual CRA table pattern consists of six columns (Event – Consequence category – Probability – Consequence – Risk – Reference), we deleted the Reference column, but included another column. This new (second) column is linking the Hazardous event (cause) to the Hazardous consequence to water quality or quantity. The reason was to demonstrate clearly the relationship between the cause and the potential consequence to water utility staff. See Appendix A for the new table arrangement. The consequence category identifies the area(s) affected by hazard and hazardous event. The consequence of the event may have impact on water quality (*a*), water supply reliability (*b*), reputation or economy of the water utility (*c*), or on a combination of 2 or 3 of these categories.

1.3.3 *Estimation of risk: FMEA/FMECA*

To assess supply reliability (in a selected part of the system – the reservoir) the Preliminary Hazard Analysis (PHA) and consequently the Failure Mode and Effects Analysis (FMEA) methods have been used by BUT to estimate the risk (Tuhovčák, 2007).

FMEA/FMECA

The major problem is always how to calculate or estimate the consequence and probability under uncertainty – lack of data, insufficient historical records and/or unreliable data, uncertainty of failure detection, uncertainty of the employed methodology of risk analysis and proper interpretation, etc. This problem may be effectively solved by using frequency instead of mathematical probability of occurrence of any undesired event and also by employing the FMEA/FMECA methodology (Failure Mode and Effects Analysis/Failure Mode, Effects and Criticality Analysis).

FMEA uses categorization of probability of occurrence, severity of consequences and all other potential inputs into categories. For instance, categories of frequency of occurrence may be as follows: almost certain – likely – moderate – unlikely – rare. The category is then represented by its point-score only, e.g. almost certain 5, rare 1. Each analyzed element is to be assigned into one of the categories. This is done based on some chosen factors or indicators and, of course, based on the limits of categories. Limits are set up by an expert with sound knowledge of the system. This is a very efficient approach especially in the situation where hard data are missing and the analysis has to be based on “soft” data (i.e. expert judgements). A semi-qualitative model is constructed where experts’ qualitative information is very effectively used together with quantitative (statistical or empirical) hard data.

FMEA and FMECA are reliability methods that enable the assigning of failures with significant consequences affecting the functionality of the system. The general methodology of FMEA/FMECA is standardized by IEC 812 (1995). Both the methods are very suitable for risk analysis of technological systems including water supply systems (WSS). Basically, the analysis begins with choosing the element from the lowest level for which

enough information is available. At this level, several tables are created describing different failure modes that may occur on each element of the level. Elements are assessed particularly one by one and the consequence of the failure of each of them is considered as a failure mode when consequences of the failure are analyzed at the next higher level. This way the analysis proceeds bottom-up-ward and the result is the assignment of consequences of the failures with the specific failure modes at all required levels up through the whole system as a unit.

Risk analysis using FMECA

The hazard catalogue which had been developing within the Czech national research project WaterRisk was used to identify the hazards. Hazards are divided into three categories (natural, social, and technological). To facilitate the identification of the individual hazards, the catalogue also includes potential consequences of the relevant hazard. Based on the identified hazards and the present system elements, the undesired events are then generated ad-hoc. For the water tanks, a total of 6 following undesired events are defined:

- damage/destruction of the civil structure of the storage tank,
- damage/destruction of civil structure of the handling chamber,
- water contamination in the storage tank,
- deteriorated water quality,
- sediment settling at the bottom of the tank,
- insufficient water storage in the tank.

The risk is quantified as a combination of the probability of an occurrence of the undesired event and its consequences.

Frequency analysis - the probability is evaluated on the basis of a set of pre-determined potential risk factors that obviously cause the undesired events. Each factor is classified by "penal" points (0 - 3 points). The final probability is then the sum of the points and on the basis of the functional regulation it is classified under one of the three categories (K1 - K3) as follows:

K1 ...	up to 33% of the maximum score
K2 ...	33 to 66% of the maximum score
K3 ...	more that 66% of the maximum score.

Further details on the frequency analysis are presented in Table 3.

Table 3: Example of frequency analysis of undesired event NS 01 – damage/destruction of the civil structure of the storage tank.

Risk factor	indication, criteria	Yes/No	Score
Storm rainfall	Concrete corrosion, reinforcement uncovering and/or corrosion	No	2
	Concrete constructions wetting	No	2
	Outer constructions uncovering - in case of high slopes	Yes	2
	Backfill washing	Yes	1
Acid precipitation	Reinforcement corrosion	No	3
	Concrete chemical corrosion - massive ruptures in the construction	Yes	2
	Concrete dropping off the wall	No	2
Snow, hailstorm, ice, coating of ice	Massive ruptures in the construction	No	3
	Ceiling plate rupture	No	3
	Concrete constructions wetting	Yes	2
	Formation of microfissure network due to freezing of moisture content in the concrete	Yes	2
	Minor damage of the outer casing (water towers)	No	1
... analysis continues by other factors (tailored for each undesired event separately)		Maximal score: 25 Total score: 9 = K2	

Consequence analysis – the consequences are divided into 4 categories (health, economic, social-economic and environmental). Their level is divided again into three categories (K1 - K3).

Risk evaluation – the final risk is the risk with the worst combination of the probability of occurrence and the individual consequences. It is also divided into three categories designating whether it is (Fig. 2):

- None or negligible risk – there are no risks to be reduced,
- As low as reasonable possible risks (ALARP) – the risks in this area are dedicated to more detailed discussions; usually cost/benefit analysis is processed and trade-off values are quantified,
- High or intolerable risk – no doubt that risk reducing measures must be taken for the risk in this area.

Risk matrix		Consequences		
Frequency	Category	K1	K2	K3
	K1	None or negligible		
	K2		ALARP	
	K3		Intolerable	

Fig. 2: Risk matrix.

1.4 Limitations

There are several limitations of the study. The whole system was assessed with the exception of the internal piping of individual buildings. Although an ideal situation asks for water safety plan(s) comprising the system from “catchment to tap”, it seems not to be feasible to analyse every single building supplied in the case of any larger public water supply within the plan developed by the water supplier. The main hazardous events and risks that

can occur within the buildings might be identified, but that has not been done in the present case study.

Beside quantitative limitation with regards to the scope or coverage of the study mentioned above, there should be mentioned also some qualitative limitations of the assessment caused by the lack of data, e.g. missing information on hydrogeology of the sources, missing confirmation of some suspected hazardous event, or issues discussed in more detail in chapter 3.3 Sensitivity analysis.

2 System description

The town Březnice is found in central Bohemia about 80 km SW of Prague, with a population of 3500. This small town is known and popular among tourists and visitors due to a nice chateau with its beautiful gardens, the old brewery (1506), unique small Jewish quarter and wonderful nature scenery nearby.

The public water system was built in 1930-1931, originally with only one source (Nouzov); two other sources were explored after the WWII (Obora, 1946; Martinice, around 1990). A schematic diagram of the water supply in Březnice is presented in Fig. 3. Beside the town Březnice, one village (Bubovice; about 200 people) is also supplied from this system – from source Nouzov. The owner of all utility infrastructures is the municipality (Březnice), but the supply system is operated under license by the professional water company Vodovody a kanalizace Beroun a.s. (VAK Beroun).

Total drinking water production in the system is 380-520 m³/day according to momentary water consumption. The water price was 34.35 CZK (1.2 EUR)/m³ (incl. VAT) in 2007.

Legal framework for drinking water supply and drinking water quality in the Czech Republic: Drinking water production and supply falls under the competence of three ministries. The Ministry of the Environment regulates the protection of water sources (through the Water Act), the Ministry of Agriculture regulates the use of water sources, drinking water production and supply to the consumer (through the Act on Water Supply and Sewage Systems for Public Needs) and the Ministry of Health regulates drinking water quality and monitoring at the tap (through the Public Health Act – PHA). Individual subjects supplying drinking water to consumers have to meet the liabilities established by the PHA, e.g. to assure compliance with the quality requirements on supplied water, and to monitor drinking water quality to the extent and as frequently as established by law. Drinking water quality may be tested by an authorized or accredited laboratory only.

During the communist regime and shortly after its fall, the whole water supply and sewerage infrastructure in the Czech Republic was owned and operated by the state enterprise “Vodovody a kanalizace” (“Water Supplies and Sewerages”). In early the 1990s, during the process of privatization of state properties, fundamental changes happened also in the sector of water management when all water supply infrastructures was passed over (transformed) from state ownership to municipalities (mostly) or to the private sector. Currently, there exist various forms of ownership and operation of the water supply infrastructure in the Czech Republic. The model in our case study site (Březnice) is as follows: the infrastructure is owned (from 1994) by the municipality of Březnice, which leased the operation of water supply and sewerage to a private company – the current operator (from 1 July 2005) is VAK Beroun – www.vakberoun.cz (a member of ENERGIE AG Wasser, joint-stock company).

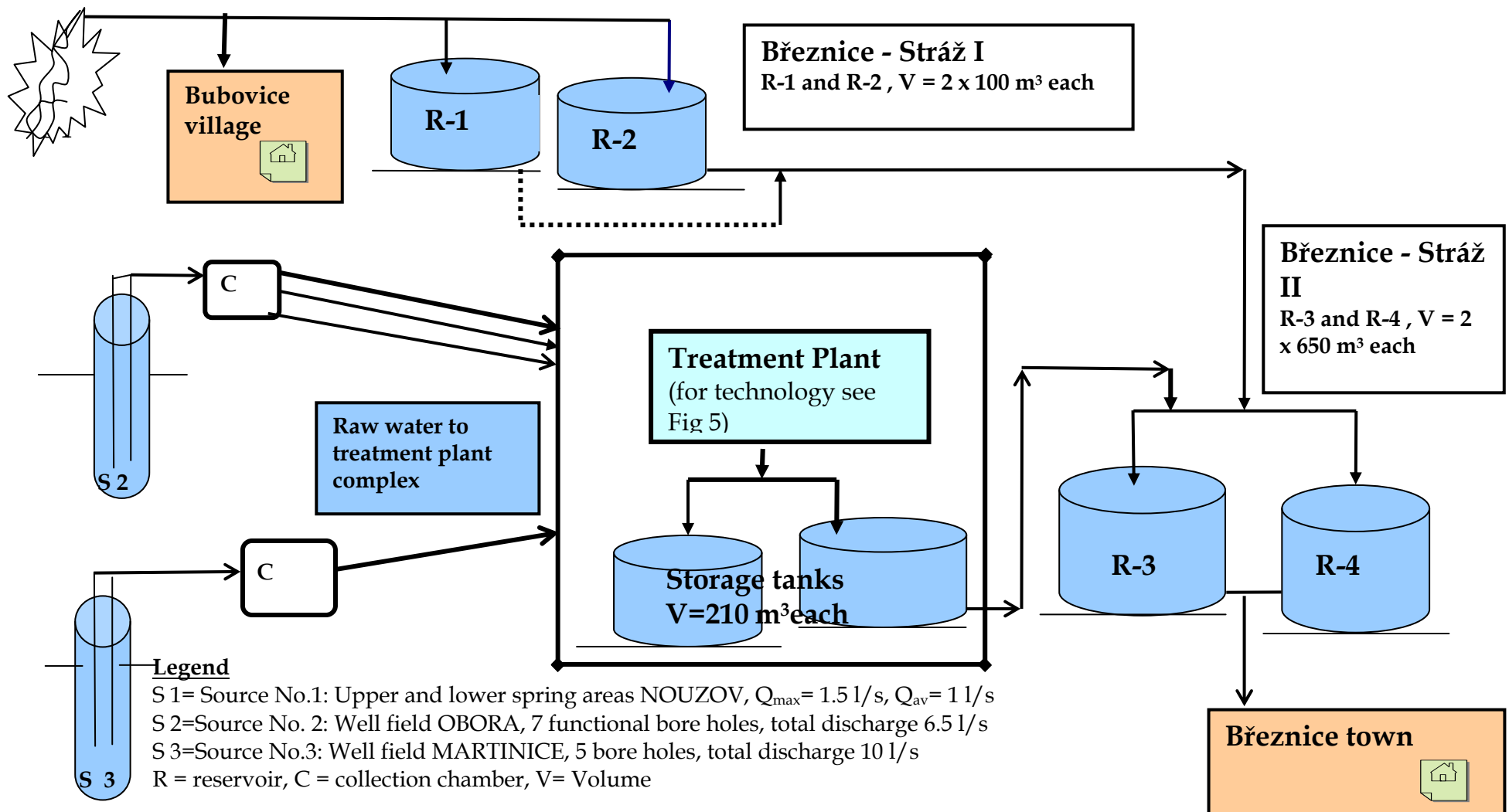


Fig. 3. Schematic diagram of the whole Březnice water supply (not scaled).

2.1 Source water

The Březnice water supply system has three groundwater sources: spring area Nouzov, well field Obora and well field Martinice (Fig. 4).

Source Nouzov (S1) consists from upper and lower spring areas. It is situated about 5 km W of the city. The total discharge of the source on average is 1 l/s (maximum discharge is 1.5 l/s); total abstraction in April 2007 was < 2000 m³. In each area water is collected from a Y-shaped subsurface gallery to a collection chamber. The upper area (S1a) is located in the forest, the area above the gallery is starting to become overgrown by trees. The lower area (S1b) is located in the midst of fields (mostly grain crop, partially cattle grazing), the area is running to weeds and bushes. Neither spring area is fenced.

Water in the collection chamber of the upper area is chlorinated by the dripping method. From the upper spring area water is led by a cast iron pipe (Ø 60 mm) to the lower area and from there by cast iron pipe (Ø 100 mm) to an old reservoir called Březnice-Stráž I, close to the city. The pipe line is not straight, but it copies old zigzag boundaries of fields, which means considerable pressure loss.

Source Obora (S2) is situated at the city border, between a small river and the castle park, very close to the treatment plant. This well field consists of 12 bore holes, from which 7 boreholes are actually in use (functional); with a total discharge of 6.5 l/s. Total abstraction in April 2007 was about 4000 m³. About half of the well field is grassed over, poorly fenced; the second part with two boreholes is located in the middle of a field (intensively cultivated land), only the boreholes as such are fenced.

The raw water from this source is directly pumped to the treatment plant using three separate plastic mains from the groups of boreholes.

Source Martinice (S3) is situated about 2 km S of the city, close to the pond. The well field consists of five active boreholes with a total discharge of 10 l/s. The depth of the boreholes is 30 to 50 m. Total abstraction in April 2007 was about 6000 m³. The field is grassed over, well fenced. Raw water from this source is pumped with one cast iron main (Ø 100 mm) to the treatment plant.

Hydrogeology. Local hydrogeological zone is generally characterized as proterozoic crystalline complexes, mostly granitoids with fissure water and low to moderate permeability. However, information on exact situation in the well fields and spring areas was not available. Alluvium may be expected in Obora well field situated by the river.

Raw water quality of the Nouzov source is considered to be of good quality, it needed no treatment, only chlorination. Raw water from Obora and Martinice has high contents of iron (on average about 0.3 mg/l, with a maximum of up to 0.7 mg/l) and manganese (on average about 0.5-0.6 mg/l, with a maximum of more than 2 mg/l) and has to be treated. The turbidity of raw water varies from 0.1 to 5.4 NTU.

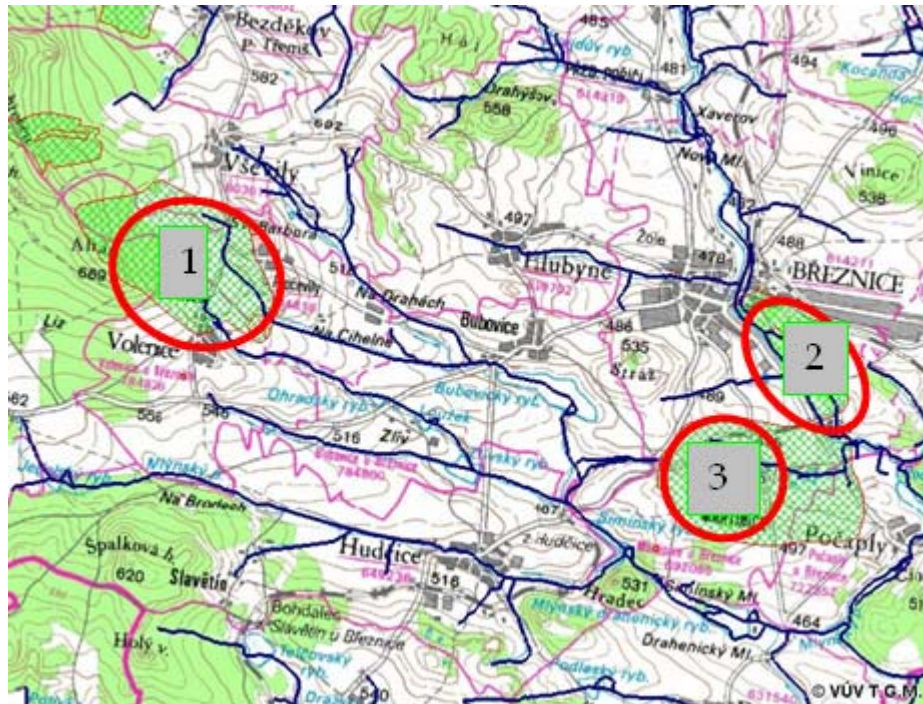


Fig. 4. Three drinking water sources and their catchments of the Březnice water supply: 1. Nouzov; 2. Obora; 3. Martinice.

2.2 Treatment

The Březnice water treatment plant was passed as capable in 1994 after 17 (!) years of building according to the original plans of the late 1970s. The building is over-dimensioned due to real needs and questionably designed as heavy beds of filters are located in the upper floor. The capacity is 25 l/s. The purpose of treatment is Fe and Mn removal. The following technological steps are used (Fig. 5): oxidation (potassium permanganate; 1.5 kg per 1600 l) – flocculation – filtration – disinfection (gas chlorine: residual about 0.6 mg/l) – accumulation to service tanker. Three parameters are operationally (manually) measured in the plant: pH, manganese, free chlorine.

There are two storage reservoirs (with a volume of 210 m³ each) in the treatment plant to accumulate treated water after treatment. Treated water from here is pumped to the new reservoir called Březnice - Stráž II, situated next to the old reservoir.

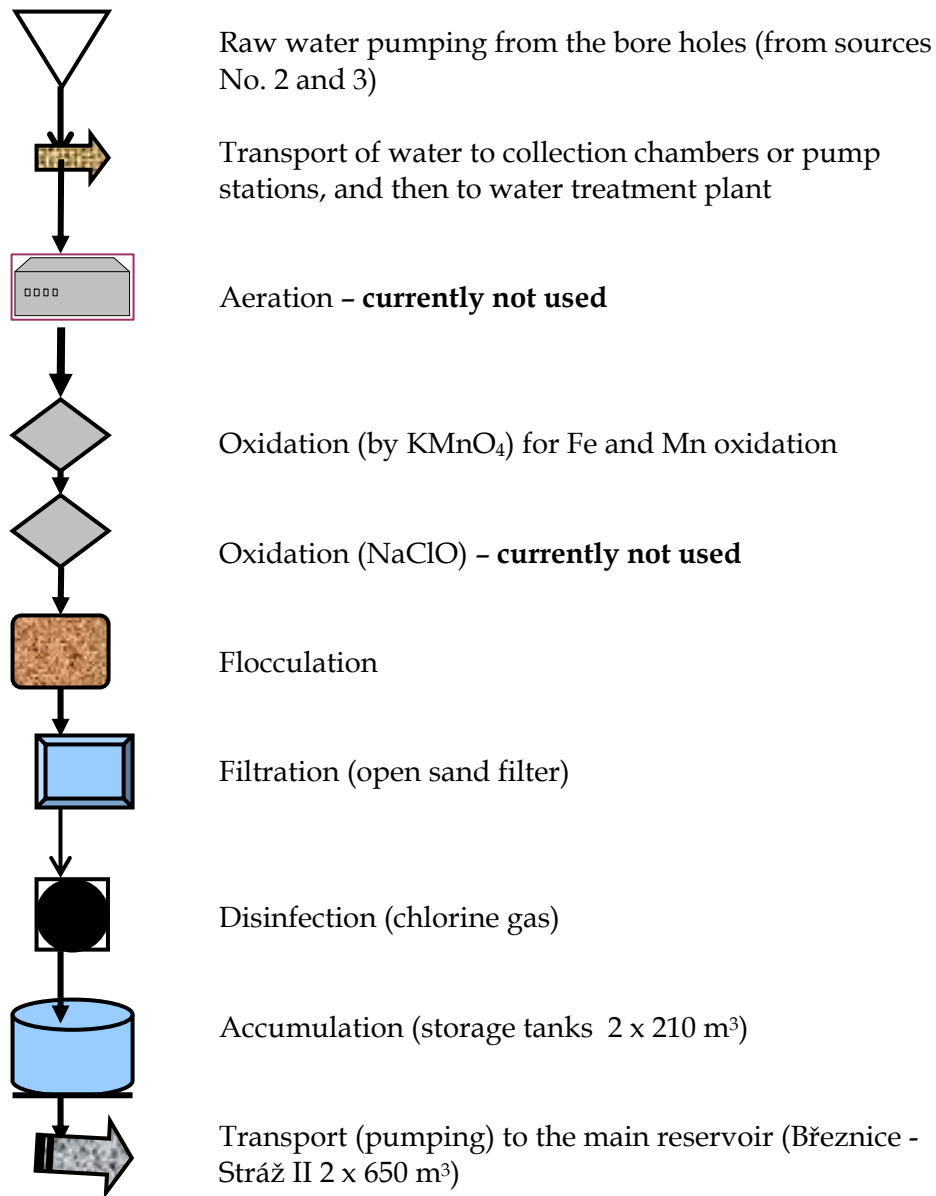


Fig. 5. Flow diagram of the Březnice water treatment plant.

2.3 Distribution

The Březnice water supply system has a network with a total pipe length about 33 km (Březnice 20.5 km; Bubovice 0.6 km; and feed-pipelines from the sources and treatment plant), see Fig. 5. Material composition of the network pipeline in the city: cast iron (all kinds) 70 %; asbestocement 25 % (includes all mains); plastic 5 %. Some service connections are still in lead. The pipe network is not a closed circuit, i.e. any main break means troublesome consequences in water delivery. Sludge removal is performed about once a month.

This network has a serious problem with high leakage about 1025.6 m³/km/year, which is about 21024 m³ per annum or 20 %.

The Březnice water supply system has the following reservoirs, beside storage reservoirs in the treatment plant (Fig. 6):

1. **Březnice – Stráž I.** It is the original (old) reservoir accumulating water from the Nouzov source, consisting of two chambers (R1 and R2) with a volume of 110 m³ capacity each. Due to high pressure losses, it serves now only as a pumping station as water from here is pumped to a newer reservoir (Březnice – Stráž II) situated about 50 meters uphill. Currently, only one chamber is used where water is disinfected by sodium hypochlorite.
2. **Březnice – Stráž II.** This reservoir was built in 1987. There are two equal chambers (R3 and R4) with a total volume of 1300 m³. Water from the Nouzov source and water from the treatment plant are mixed here. It serves as the main or true reservoir as water is distributed from here to the consumers in the city by gravity. Estimated retention time is about 3 days.

There are two pressure zones in the system: Bubovice village and Březnice town (pressure ≥ 3 atm, average 6.5 atm).

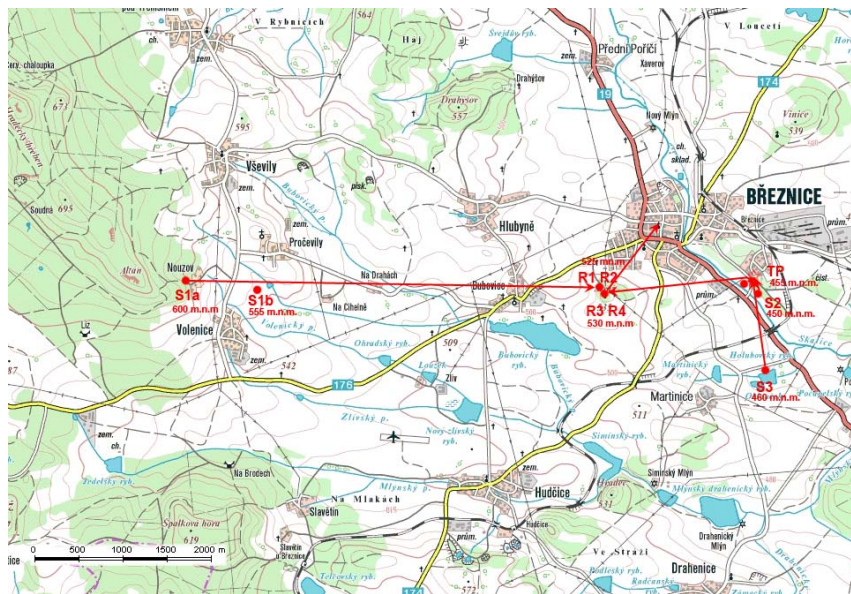


Fig. 6. Schematic plan of main pipes connecting sources, treatment plant, reservoirs and supply zone.

Water quality monitoring and analysis of water quality data:

The utility monitors water quality at the taps in Březnice and Bubovice in the scope and frequency given by the Drinking Water Directive. Moreover, they monitor also treated water leaving the treatment plant (monthly, about 20 parameters) and raw water in the sources (annually, about 20 parameters). The service of the treatment plant monitors on a daily basis, (3-4 analyses per day) pH, manganese and free chlorine in both raw and treated water.

We analysed data on water quality in the network (tap) for the period 2001-2006 and data on raw water quality from 2006.

There is good compliance regarding water quality requirements in the Březnice network. There are rare exceedings of the limits of iron and manganese or free chlorine; colony counts were higher only twice (2001 and 2002), otherwise normal values of colony counts were < 100 CFU/ml or even < 10 CFU/ml.

However, the situation in the Nouzov source and Bubovice village is different and worse: from 26 samples in 2006 there were:

- 11 non-compliance for coliforms (max. 200 CFU/100 ml),
- 4 non-compliance for E. coli (max. 10 CFU/100 ml),
- 1 non-compliance for enterococci,
- 8 non-compliance for either colony counts at 22 or 36 °C.

2.4 Earlier incidents and problems

The operator of the Březnice water supply records about 20 failures or accidents per year. The list of accidents and failures is part of the annual report.

According to the operator there are several problematic issues. The utility sees the main problem in the city network: some (3-4) parts are - due to hydraulics and not well functioning valves - difficult to desludge; mains of asbestocement are readily susceptible to breaks. Other problems described are, e.g. slow degradation of the Nouzov upper spring area (the ground above the galleries is eroded by trees, which are not allowed to be cut down); wrong design of the building of the treatment plant; ventilation in the new reservoir is not working; absence of investment policy of the municipality as infrastructure owner.

According to the local public health authority the only problem is occasional non-compliance of iron, manganese, free chlorine, and rare non-compliance of some microbiological indicators. A possible problem might be caused by old underground pollution in the area of the Opora well field.

3 Risk analysis

3.1 Hazard identification

Three detailed field visits covering all sources, treatment plant and reservoirs were carried out. Tools to identify hazards for water quality were listed in section 1.3 Methodology.

In total, 47 different hazards/ hazardous events were finally identified: 25 for sources, 11 for treatment and treatment plant building and 11 for distribution network including reservoirs. However, at 3 hazards no impact on water quality has been assumed and therefore risk rating has not been evaluated. A table listing most of these hazards is included in Appendix A. Five hazards are not listed there (4 for sources and 1 for reservoirs), because of sensitivity of such information regarding the risk of sabotage.

A specialized inspection of the water reservoir focused on reliability identified the following defects:

Storage tank:

- Corrosion of the metallic parts of the water tanks
- It is not possible to measure the level in case of power outage , no back-up source
- Non-functioning ventilation of the water tanks
- Leakage in the inlet openings to the water storage tanks
- The tanks are not regularly inspected
- Non-existence of an operating log book
- Water mixing in the water storage tanks is not checked
- The quantity of chlorine is not checked, the last check is performed at the water treatment plant
- Missing odour closure on the overflow pipe
- Unsuitable design of the discharge pipe, there is dead room in the tank of approx. 8 m³, which is cleaned once a year
- No scraping is made on the walls or bottom of the storage tanks

Handling chamber:

- Corrosion of the metallic parts of the water tank handling chamber
- Non-functioning ventilation of the handling chamber
- Condensation of air humidity at the ceiling of the handling chamber and cold pipes
- Pipe corrosion in the water tank handling chamber
- Great volumes of algae on the walls of the water tank handling chamber
- Falling off plaster and flaking of the concrete parts of the water tank handling chamber
- Uncovered steel reinforcement
- Corrosion of steel reinforcement
- Damage to the drainage pavement around the water tank handling chamber
- Non-existing communication channels (information about the access of unauthorised personnel, etc.)
- Corrosion of the entrance door to the water tank handling chamber

- Leaking entries between the handling chamber and the water tank storage tanks
- Open windows from the storage tanks to the handling chamber.
- Occurrence of dripstones on the roof of the handling chamber of the water tank
- Clogged dewatering system of the handling chamber of the water tank

These defects may cause the following undesired events (NS¹):

- NS 01: damage/destruction of the civil structure of the storage tank (probability K2, consequence K2),
- NS 02: damage/destruction of the civil structure of the handling chamber (probability K2, consequence K2),
- NS 05: deteriorated water quality (probability K2, consequence K2).

All undesired events were ranked as medium risk (according to the FMEA/FMECA method), open for further discussion using the ALARP² principle. In Appendix B the results of the analysis (FMEA/FMECA) of the reservoir are further described.

3.2 Risk estimation

The matrix used for risk estimation is described in section 1.3 Methodology. During the estimation process, several probable hazardous events were investigated in more detail to confirm or exclude suspicion (or assess the extent of the problem).

For example, the wells in Obora may be susceptible to contamination from the small river, which is flowing just along the well field. The river may be polluted, e.g. by a traffic accident, but it was really polluted by PCBs in the 1980s from the industrial setting located about 5 km upstream. However, specific analysis from the wells situated close to the river did not reveal any presence of PCBs.

Another example: We suspected some wells in the Obora well field of pesticide contamination as the SE part of the well field is surrounded by a field with intensive agriculture. We attempted to find the records on all substances applied there, but only with partial success. The Regional Public Health Authority obtained some records on chemical treatment from the farmer, however, it was not fully clear what chemicals had been really used here and if the records were properly updated or if these were the proper records for the given field (because of discrepancies in plant species recorded and those observed in reality). Special analysis was therefore ordered – substances analysed came partially from the records, partially from the general list of pesticides used for rape treatment, which was grown there in the spring of 2007:alachlor, metazachlor, chlorpyrifos, glyphosat, tebuconazole and cypermethrin. Sampling was done at the end of August, which means long after the vegetation season and pesticide treatment. All the substances were found below the detection limit. However, the risk cannot be fully disregarded, because of uncertainties about the substances applied, because of the sampling time being well after the application and due to uncertainty about

¹ NS is abbrev. from Czech “nežádoucí stav” (= undesired event)

² ALARP = as low as reasonably practicable

permeability of soil and subsurface geological structures. On the other side, we did not classify the consequences as seriously as we originally contemplated.

In total, 47 different hazards were identified, however, at 3 hazards no impact on water quality is assumed and therefore, their risk ratings were not evaluated and included in the summary table (Table 4).

Table 4: Risk ratings for Březnice water supply

Part of the system	Risk rating				
	Extreme (E)	High (H)	Moderate (M)	Low (L)	TOTAL
Sources	1	9	7	7	24
Treatment	0	2	4	4	10
Network	0	4	5	1	10
TOTAL	1	15	16	12	44

From a total of 44 hazards estimated 1 was classified as "extreme risk", 15 as "high risk", 16 as "moderate risk" and 12 as "low risk" (Table 4). For the risks rated as extreme or high risk, reduction options will be suggested. The risks rated as moderate will be discussed with stakeholders whether any risk reduction options are needed or not.

3.3 Sensitivity analysis

Usually some inherent uncertainty is associated with any hazards identification and risk assessment. Uncertainty can be caused by a lack of knowledge or by variability in parameters. Characterising the major sources and types of uncertainty can provide a better understanding of the limitations or reliability of the hazard identification and risk assessment, and how these limitations can be reduced.

As the way of analysis was not quantitative, but only semi-quantitative, possible variability in parameters probably did not substantially affect the results. The main uncertainty relates to the assessment of probability of the consequence of hazard(s) identified. We are sure about a part of the hazards and hazardous events that they really exist. In another part, we know that hazards / hazardous events may be present, but we have no evidence about the occurrence and it is not easy to verify all of them. Finally, the third group of hazards/ hazardous events cannot be excluded - they may happen, but they have never happened so far - however, it is very difficult to assess the reliability of their probability.

4 Risk evaluation

4.1 Risk tolerability

The water utility (VAK Beroun) has not developed any specific risk tolerability criteria, but generally it may be said that any risk leading to permanent non-compliance of any water quality parameter, to frequent consumer's complaints, or even to any health problems is unacceptable for both the water utility and the Public Health Authority. It was agreed within the WSP team that both extreme and high risks would be considered as unacceptable and therefore risk reduction options will be developed for all extreme (1) and high (15) risks identified, while all low risks would be considered as acceptable. Regarding the moderate risks it was agreed to apply the ALARP principle (As Low As Reasonably Practicable), i.e. the necessity of risk reduction options for these risks (16) would be discussed on a case by case basis. Some of these risks may be accepted if it is economically and/or technically unreasonable to reduce them (Techneau, 2007), but a monitoring option for such risks should be suggested.

4.2 Risk reduction options

Definition of risk reduction options and discussion about the risks in the ALARP region will be subject of the second part of the development of a water safety plan in Březnice in 2008.

5 Discussion and conclusions

5.1 Methods evaluation

Table 5 summarizes some general criteria of method evaluation and provides an overview of the applied CRA method. An x indicates low, medium or high for each criterion. However, the scale (low, medium and high) is subjective; of course, it may give some overall picture.

Table 5. Summary of the method evaluation by means of general 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 *1)	
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 *1)	
Ability to consider uncertainties of e.g. probabilities	x		
Ability to consider/model risk reduction options	*2)	*2)	*2)
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		

*1) ability would be high if FMEA/FMECA is used

*2) not assessed at this stage of the study

Resources

- Medium level of expertise needed.
- Time required for setting up risk analysis model: weeks.
- Time required for information/data collection: days to weeks (dependent on complexity and size of the system).
- Required software: normal office software just for documentation of work and results.

Method properties

- Good ability to consider a source-to-tap approach.
- Medium ability to consider interactions between events, i.e. chains of events.
- Good ability to acknowledge system structure/design.
- Limited ability to consider uncertainties of e.g. probabilities (e.g. question of duration of the undesired event and its inclusion in frequency estimation).
- Required input data (hard data and/or expert opinions): according to the system size and complexity, but expert opinion or very good knowledge of the system is needed.
- Ability to account for tolerability criteria: not assessed at this stage.
- Ability to consider risk-reduction efficiency: not assessed at this stage.
- Good ability to be integrated in the water company management/maintenance routines:
- Good updating possibilities, i.e. update when new information becomes available.

Results provided by the method

- Type of prioritisation of risks: relative ranking.
- Good ability to provide understandable results to the specific end-user.
- The usefulness of the results for the specific end-user: yes.
- The precision of the results: medium.
- Time frame of which the results remain accurate: dependent on external changes or ageing of the system, but several years under normal situation. Nevertheless, annual screening inspection of all parts of the system is recommendable.
- Limited ability to provide input data to be used in further studies (e.g. more detailed risk analysis), but it may be useful for identification of most priority subjects for a further more detailed assessment.

Types of decision-making the methods can assist in

- Relative ranking of risks: yes.
- Comparison of risk levels to established tolerability criteria: yes.
- Cost-efficiency analysis: limited.
- Cost-benefit analysis: limited.
- Operational decisions: yes.
- Strategic decisions: partially.

5.2 Lessons learned

- A perfect knowledge of the whole water system is vital for reliable hazard identification as well as risk estimation. The best option is cooperation between operator working daily with the system and some expert with

good knowledge background in water quality and water contamination sources.

- In case of small and relatively simple systems, the risk analysis can be done quite easily (with the help of guidelines) even by some not very experienced person. Even when the reliability may not be very high it is a good start leading to getting proper experience. It is the basis for further development.
- If any hazard checklist or database is used for hazard identification, it is recommended to users to read it (proper part) before visiting the system (of part of the system) and again after the visit. During the field visit there is not usually time enough to study the checklist or even database.
- Somebody, who has little experience in risk analysis, can identify many possible (or theoretical) hazards according to the hazard database, but it is necessary then to verify or exclude (some or most of) them, e.g. through focused and more detailed analysis, to obtain a reasonable list of real hazards for further evaluation and work.
- Most hazards might be identified (by means of hazard checklist or database) by somebody with a general knowledge on water supply, but some hazards (e.g. many hazards on special treatment steps like coagulation/flocculation, filtration or filtration) can be identified only by a very good specialist in water treatment and chemistry or in hydraulics.

5.3 Conclusion

Within our assessment, which covered the whole supply system from the sources to service connection, we identified quite comprehensive list of hazards (44) which have been further classified and expressed as "extreme risk" (1), "high risk" (15), moderate risk" (16) and "low risk" (12).

As the water utility (VAK Beroun) has not developed any own specific risk tolerability criteria, it was agreed within the WSP team that both extreme and high risks would be considered as unacceptable, and therefore, risk reduction options will be developed for all extreme and high risks identified, while all low risks would be considered as acceptable. Regarding the moderate risks, it was agreed to apply the ALARP principle, i.e. the necessity of risk reduction options for these risks would be discussed on a case by case basis. Some of these risks may be accepted if it is economically and/or technically unreasonable to reduce them, but a monitoring option for such risks should be suggested.

The CRA (Coarse Risk Analysis) method used in this case study seems to be a suitable tool for risk identification and estimation in small water supplies. It may be completed or replaced by a more sophisticated method at a later stage, but for the initial risk assessment process it represents a reasonable approach due to expertise, technical and financial requirements on the one side, but with sufficient sensitivity on the other.

6 References

Davison A., Howard G., Stevens M., Allan P., Fewtrell L., Deere D., Bartram J. (2005), Water Safety Plans. Managing drinking-water quality from catchment to consumer. (WHO/SDE/WSH/05.06). WHO, Geneva.
http://www.who.int/water_sanitation_health/en/

IWA (International Water Association) (2004), The Bonn Charter for Safe Drinking Water. <http://www.iwahq.org/uploads/bonn%20charter/BonnCharter.pdf>

Standard IEC 812 (1995) Analysis Techniques for System Reliability - Procedure for Failure Mode Effects Analysis.

SVGW (2003), Recommendations for a simple quality assurance system for water supplies (WQS). Regulation W 1002e. Schweizerischer Verein des Gas- und Wasserfaches SVGW, Zürich.

Rosén L., Hokstad P., Lindhe A., Sklet S., Rostum J. (2007): Generic Framework and Methods for Integrated Risk Management in Water Safety Plans. edited by Chalmers, SINTEF: Deliverable Nr. D4.1.3 / D4.2.1 / D4.2.2 / D4.2.3. TECHNEAU

Tuhovčák, L., and Ručka, J. (2007), Hazard identification and risk analysis of water supply systems, Proceedings from the LESAM IWA Leading Edge Conference on Strategic Asset Management 2007, Lisbon, Portugal, 10/2007, ISBN: 1843391864.

Appendix A – List of identified hazards by CRA method

All but 5 hazards are listed here. The missing hazards (4 for sources and 1 for reservoirs) present sensitive information with regard to the risk of sabotage.

Risk analysis of the hazards identified with use of the Coarse Risk Analysis method – results

Sources:

Hazardous event/ cause	Hazard/ potential consequences to water quality/quantity	Consequence category	Likelihood	Consequence (severity)	Risk
Source Nouzov					
Heavy rainfall (see also hazards listed below). There is forest area in the catchment of the upper spring area where pathogen contamination from wild animals may occur. There is continuous degradation of the upper collection gallery (roots of the trees, no repairs allowed). Regarding the lower spring area, there may be more hazards (from farm animals).	Higher turbidity and microbial contamination of water distributed. It is not known if water quality deterioration after heavy rainfall is caused by both spring areas or just by one of them. The way, how this source is shut down (when visible turbidity of water in Bubovice village appears – this information is usually provided by one employee family living in Bubovice) cannot protect consumers sufficiently as it is almost clear that at the time of visible turbidity occurrence the water had been probably microbiologically contaminated already.	<i>a</i>	D	4	H
Mechanism of disinfection applied (water in collection chamber of the upper area is chlorinated by the dripping method, because there is no electricity available) does not	Disinfection is not efficient. Microbially contaminated water may be distributed to Bučovice village and the water reservoirs.	<i>a</i>	D	4	H

Hazardous event/ cause	Hazard/ potential consequences to water quality/quantity	Consequence category	Likelihood	Consequence (severity)	Risk
allow to react to any change in flow or water quality.					
Pasture of farm animals (cows) in meadows around the lower spring area	Microbiologically contaminated source water after heavy rainfalls.	<i>a</i>	D	4	H
Extensive agricultural activity very close to the lower spring area (rape, maize)	Pesticide contamination of source water.	<i>a</i>	D	2-4	M
Long period without rainfall.	Lower capacity (yield) of the resource.	<i>b, c</i>	D	1	L
<i>not listed</i>					
Collection chamber in the lower spring area is accessible only with difficulty because of luxuriant vegetation (bushes). The chamber is slowly deteriorating by the roots. Water is not disinfected and the chamber integrity is controlled only rarely.	Microbiologically contaminated source water after rainfalls. Contrary to the other two sources which water is mixed in water reservoirs with other sources, water from the Nouzov spring area is directly supplied in Bubovice village.	<i>a, b</i>	E	4	H
There are probably still parts of the trunk main with bitumen inner lining.	Leaching of PAH into water.	<i>a</i>	C	2	M
Breaks in the trunk main (spring area - water reservoir).	Interruption of supply from the Nouzov source.	<i>b, c</i>	D	3	M
Source Obora					
Small river is flowing just along the well field. It may be polluted	Serious contamination of the river may cause contamination of the wells nearby.	<i>a</i>	E	2	L

Hazardous event/ cause	Hazard/ potential consequences to water quality/quantity	Consequence category	Likelihood	Consequence (severity)	Risk
by, e.g. a traffic accident. The river was really polluted by PCBs in the 1980s from an industrial setting located about 5 km upstream. <i>However specific analysis from the wells situated close to the river did not reveal any presence of PCBs.</i>					
Flood from the river flowing by after heavy rainfalls.	Flooded well field causing primarily microbiological contamination of source water and its shutting down.	<i>a, b</i>	E	3	M
The well field is situated in a shallow valley with several industrial enterprises around up the hills which might contaminate groundwater. This pollution (organic substances and metals from galvanize operation; organics from wood treatment) was confirmed in the past. <i>Analysis of samples taken in August 2007 did not reveal any presence of TCE or PCE in wells No. 4+5; concentration in wells 6+8 were slightly above the limit of quantification (0.4 and 0.6 µg/l). Analysis for metals revealed an expected high concentration of manganese and partially iron,</i>	Chemical contamination of source water.	<i>a</i>	D	2	L

Hazardous event/ cause	Hazard/ potential consequences to water quality/quantity	Consequence category	Likelihood	Consequence (severity)	Risk
<i>however, of the heavy metals only mercury was found (at a level of about 30-40 % of the limit value). Because of blending of the sources, mercury concentration in tap water is below the limit of detection. Nevertheless, when considering future use of the Obora source, it should be taken into account.</i>					
Natural high content of iron and manganese in raw water (Fe up to 0.7 mg/l; Mn up to 2 mg/l) due to geological conditions.	Short life-span of the pumps (1-2 years).	<i>c</i>	D	No impact on water quality	-
Natural high content of iron and manganese in raw water (Fe up to 0.7 mg/l; Mn up to 2 mg/l) due to geological conditions.	Compromised sensoric acceptability of water at the tap if treatment is not sufficient.	<i>a</i>	B	3	H
Construction integrity of some wells is in bad condition – breaks in the ceilings of well-head chamber around the cover; ingress of surface water in the chamber, standing water in the chamber, access of small animals.	Microbiological contamination of water in sources.	<i>a</i>	B	4	E
<i>not listed</i>					
<i>not listed</i>					
SE part of the well field is surrounded by a field with	Contamination of source water with pesticides.	<i>a</i>	D	3	M

Hazardous event/ cause	Hazard/ potential consequences to water quality/quantity	Consequence category	Likelihood	Consequence (severity)	Risk
<p>intensive agriculture.</p> <p><i>We attempted to find the records on all substances applied here, but only with partial success. The Regional Public Health Authority obtained some records on chemical treatment from the farmer, however, it was not fully clear what chemicals had been really used here and if the records were properly updated or if these were the proper records for the given field (because of discrepancies in plant species recorded and those observed in reality). Special analysis was therefore ordered – substances analysed came partially from the records, partially from the general list of pesticides used for rape treatment, which was grown there in the spring of 2007:alachlor, metazachlor, chlorpyrifos, glyphosat, tebuconazole a cypermethrin. Sampling was done at the end of August, that means long after the vegetation season and pesticide treatment. All the substances were found below the detection limit. However, the risk cannot be disregarded, because of uncertainties</i></p>					

Hazardous event/ cause	Hazard/ potential consequences to water quality/quantity	Consequence category	Likelihood	Consequence (severity)	Risk
<i>about the substances applied, because of the sampling time well after the application, and due to uncertainty about permeability of soil and subsurface geological structures.</i>					
There is a main sewage collection pipe from the town put in the ground along the well field leading to the WWTP nearby.	In case of break of the sewage main, microbiological contamination of water in the sources may occur.	<i>a</i>	E	4	H
Source Martinice					
Ingress of surface or subsurface water into the well (standing water in well-head chamber No 3 was about 5 cm from the rim of casing.	Microbiological contamination of water in sources.	<i>a</i>	D	3	M
Arable fields around the well field.	Contamination of source water with pesticides? (We do not know if it is, due to hydrogeological conditions, possible.)	<i>a</i>	D	2	L
Village Martinice is located several hundred meters from the well field.	Microbiological contamination of water in sources? (We do not know if it is, due to hydrogeological conditions, possible.)	<i>a</i>	D-E	2-4	L
<i>not listed</i>					
Raw water had high content of iron and manganese.	Pump failure (short life-span of the pumps: 3-5 years).	<i>b, c</i>	E	2	L
There is a road some 50 m away from the well field.	Pollution from traffic (oil products, accidents).	<i>a</i>	E	2-4	L

Water treatment:

Hazard	Hazardous event	Consequence category	Likelihood	Consequence	Risk
Treatment - general risks					
Unsuitable design of the building (filter beds are situated in the upper floor of the building, beds are leaking).	Compromised statics of the building. Risk of emergency shut down of the building and treatment process.	<i>a, b, c</i>	E	4	H
The building is oversized due to its function and needs.	Costly and not efficient heating of the building in winter.	<i>c</i>	-	-	-
Water from filter beds is leaking to the groundfloor.	Occurrence of algae and moulds on walls in the groundfloor. Water quality may be influenced (taste, odor, biology).	<i>a, c</i>	B	2	H
Water from filter beds is leaking to the groundfloor.	Corrosion of pipes and valves.	<i>a, b, c</i>	D	3	M
Sampling points (valves) are situated in a remote part of the building, not easily accessible.	Delay in action in an emergency.	<i>a</i>	D	1	L
Treatment - technology					
Wrong dosage of potassium permanganate (KMnO ₄) - with respect of actual raw water quality - caused by mistake in analysis (low reliability of rough colorimetry test; laboratory mistake) or by sudden change between two analyses.	Iron/manganese removal not efficient, lower organoleptic quality of drinking water (turbidity, colour), higher occurrence of sediments (turbidity) in distribution network.	<i>a, c</i>	D	2	L

Hazard	Hazardous event	Consequence category	Likelihood	Consequence	Risk
Wrong dosage of potassium permanganate(KMnO ₄) - with respect of actual raw water quality - caused by wrong function or wrong setting of dosing equipment.	Efficiency of Fe/Mn removal is lower due to suboptimal operational conditions (Fe/Mn oxidation process not sufficient). Lower organoleptic quality of drinking water (turbidity, colour), higher occurrence of sediments (turbidity) in distribution network.	a, c	D	2	L
Automatic operation control system is switched off during storms and lightning.	Operation of treatment is switched to manual control; risk of lower efficiency of treatment or treatment interruption. <i>However, because of long retention time of water in the reservoir and supply from the 3rd source (Nouzov, not treated), interruption of supply of water to consumers is not supposed.</i>	a, b, c	C	2	M
Interruption in electricity supply during storms.	Interruption of water treatment and delivery of treated water in reservoir. <i>However, because of long retention time of water in the reservoir and supply from the 3rd source (Nouzov, not treated), interruption of supply of water to consumers is not supposed.</i>	b, c	D	2	L
Wrong function of chlorination, because of device failure, power failure or wrong setting of dose in relation to raw water quality.	Disinfection is not efficient, microbiologically contaminated water may be pumped to the reservoirs.	a, c	D	3	M

Hazard	Hazardous event	Consequence category	Likelihood	Consequence	Risk
Water treatment lower staff (with exception of chief technologist) has no proper knowledge about the function of all technological steps and operational devices.	In case of unexpected event when chief technologist is not present, the staff does not act properly to new situation.	<i>a</i>	D	3	M

Distribution network:

Hazard	Hazardous event	Consequence category	Probability	Consequence	Risk
Water reservoirs					
<i>not listed</i>					
Ventilation shaft above old reservoir compartments have not properly covered vents (bad technical status of grating covering the vents).	Contamination of water (mostly microbiological due to possible access of birds, rodents and other small animals).	<i>a</i>	D	3	M
Ventilation in new reservoir is out of operation.	High humidity, water standing on the floors, growth of algae and micromycetes and bacteria on the walls (possible contamination of water by air within the reservoir).	<i>a</i>	C	2	M
Ventilation in new reservoir is out of operation.	High humidity, water standing on the floors. Corrosion of valves and other technical equipment. Technical operation may be difficult.	<i>b, c</i>	-	-	-
Stagnation of water in new reservoir (up to 3 days). There is "dead" space about 8 m ³ by the bottom of the reservoir.	Continuing oxidation of water and formation of iron and manganese sediments - suitable conditions for microbial growth.	<i>a, c</i>	C	2	M

Hazard	Hazardous event	Consequence category	Probability	Consequence	Risk
Insufficient insulation of new reservoir.	Increase of water temperature in summer period, lower content of chlorine residual, microbial regrowth, possible influence on organoleptic qualities of water.	<i>a, c</i>	D	2	L
Distribution network (Březnice)					
Distribution network is not circled (no ring).	In case of any pipe break, supply to whole following branch of network is interrupted.	<i>b, c</i>	D	3	M
Network design and wrong function of some valves do not allow proper flushing (desludge) of all parts of the network.	Compromised sensoric acceptability of water (turbidity, colour, taste).	<i>a, c</i>	C (B)	3	H
High water losses in network suggest compromised tightness of the pipes or joints.	Possible (mainly microbiological) contamination of water in pipes when pressure drops (sucking of polluted groundwater)	<i>a</i>	D	3	H
Unsuitable material of part of the network from mechanical reliability point of view (asbestocement, old cast iron, lead service connections).	Deformation or break of the pipe during building activities or by heavy transport. Compromised integrity of the pipes with supply interruption or water contamination.	<i>(a), b, c</i>	D	4	H
Unsuitable material of part of the network from the water quality point of view (steel with bitumen lining, cast iron without any inner lining, lead service connections).	Contamination of water with chemicals (PAH, lead, iron), corrosion and high turbidity, lower efficiency of chlorine residual.	<i>a</i>	C	2	M

Symbols used:

Consequence category: *a* = Water quality; *b* = Water supply; *c* = Reputation/economy

Probability (likelihood or frequency): A = Almost certain (once a day); B = Likely (once per week); C = Moderate (once per month); D = Unlikely (once per year); E = Rare (once every 5 years)

Consequence/impact: 1 = Insignificant (no detectable impact); 2 = Minor (minor aesthetic impact causing dissatisfaction but not likely to lead to use of alternative less safe sources); 3 = Moderate (major aesthetic impact possibly resulting in use of alternative but unsafe water sources); 4 = Major (morbidity expected from consuming water); 5 = Catastrophic (mortality expected from consuming water)

Risk rating: E - Extreme risk, immediate action required; H - High risk, management attention needed; M - Moderate risk, management responsibility must be specified; L - Low risk, managed by routine procedures.

Appendix B – List of identified hazards by FMEA/FMECA method

Risk analysis of the hazards identified with use of the FMEA/FMECA for service reservoir – results (see 1.3.3)

The following undesired events have been identified:

NS³ 01 – damage/destruction of the civil structure of the storage tank;

NS 02 – deterioration of water quality in accumulation/storage tank;

NS 05 – damage/destruction of the civil structure of the manipulation chamber of the reservoir.

Based on the results of risk analysis it can be stated that service reservoir does not require immediate reconstruction, but for the prolongation of the life and operational capability of the reservoir, some safety measures should be taken. Non-functional ventilation system and uptightness of the inlets to the accumulation tank or reservoir can be seen as a problem; where water is stagnated in the lower part of the system. As the result of these both problems there is high moisture (wet) in the system and due to this there is a growth of algae and moulds. Another problem, which needs solution, is a lack of safety control remote system of the reservoir or water storage chamber (a possibility of devastation of the system, or intentional water contamination; late intervention by fire brigade in case of fire. The dead volume or space (about 8 m³) under the sucking basket may present water quality problem.

³ NS is abbrev. from Czech “nežádoucí stav” (= undesired event).